Kaumera as flame retardant – the opportunities and obstacles to societal implementation according to the SBMI comparing it to the Lean Startup Model

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TU Delft Biotechnology and Society

Master's thesis (Life Science and Technology) – LM3901

1-9-2023 until 26-8-2024

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This thesis contributes to the European Union's Horizon 2020 research and innovation programme WATER-MINING - Next generation water-smart management systems: large scale demonstrations for a circular economy and society, which received funding under Grant Agreement no. 869474.

Abstract

Kaumera is a material made from wastewater treatment and has shown promising characteristic as a flame retardant. In this research report we aimed to bridge the gap between academia and commerce by analysing the potential of Kaumera using a generalised framework of Sustainable Business Model Innovation and the Lean Startup Methodology. The named models were researched through the method of research through design. Using the SBMI framework of Bocken (2019) a startup was proposed and compared to the Lean Startup Methodology. As defined by the SBMI framework, the symbiotic dependencies were identified to be the producers of Kaumera, the clients of the company, the IP owners, academics involved and potential partners. The neutral dependency is related to legislation and legislative bodies, and the competitive dependency are competitors. Furthermore, it was analysed how the assumptions could be validated by the company for the early-stage, scaling and diversification and internationalisation phases of the company.

The results found that Kaumera is a feasible flame retardant both in a commercial and sustainability perspective. It was found that the SMBI framework focusses too much on the sustainability aspect to be truly a viable Business Model approach for startups and does not allow for flexible and adjustable business strategies. For this reason, a combination with the Lean methodology can be applied to overcome the shortcomings of the SBMI framework. This research report shows that the Lean methodology complements the aspects of SBMI which are not suited for startups. This research report therefore suggests the use of a framework based on Lean incorporating generalised aspects of SBMI as an effective and flexible sustainable business model for startups.

Acknowledgements

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1.1 - Introduction

In the European Union (EU), one of the hottest topics regarding safety is the matter of polyfluoroalkyl substances (PFAS) and halogens. PFAS is a group of compounds containing chains of carbon-fluor bonds. It is a very persistent molecule and is frequently used in the fire safety industry, however, there is a movement within EU regulatory bodies to completely ban PFAS (*ECHA Identifies Certain Brominated Flame Retardants as Candidates for Restriction*, 2023). Another compound that is being phased out are halogens which are commonly used in flame retardants. The phenomenon where an effective fire extinguishing or flame retarding component is shown to be devastating to human health and the environment has historically happened many times in the fire safety industry and related fields. Examples are asbestos and methyl bromide.

Currently, the fire safety industry is forcibly moving away again from halogens and PFAS by restricting its use, which should lower the impact on the environment (U.N. environment programme, 2017). This lowers the impact the fire safety industry has on the environment, but there are still environmental improvements to be made. After all, most of the fire extinguishing chemicals and the closely related flame retardant chemicals used in the construction industry are very dependent on fossil fuels (DSouza et al., 2023). There is research being performed into biobased and circular fire safety chemicals, such as Kaumera. Kaumera is a resource obtained from wastewater treatment plants and is proven to be an effective flame retardant. It has the potential to make the fire safety industry much more sustainable without any compromise in effectiveness.

The fact that there is scientific indication that a material might be an effective flame retardant, does not mean that the product will make a significant positive impact on society. There is a barrier between academic and the commercial world, which means that there are significant hurdles to overcome before a product is successful in the commercial environment. To academically analyse the advantages of a product and how it would perform on the market, a business model can be constructed. This allows one to research the product and lowers the barrier of entry for a business attempting to put this product on the market. This method is called “research through design” (Baldassarre et al., 2017; Joost et al., 2016; Stappers, 2012; Zimmerman & Forlizzi, 2008)**.** This way the gap between the academic and commercial world can be bridged by gathering data on both the business model as well as Kaumera and its implementation onto society. This will allow one to get empirical data on the business model by using it and it will allow the user to give an academic view on the implementation of Kaumera whilst taking the commercial side into account.

There are a lot of business models being used in the academic and the commercial world. Some focus solely on the financial possibilities, whilst others focus mostly on the societal impact the business would have. Ideally, the would be a model that perfectly incorporates both sides, since the business needs to be viable, but it also needs to be societally conscious and maximise its positive impact. The business model that was used is a generalised framework of Sustainable Business Model Innovation (SBMI) (N. Bocken et al., 2019). This framework is a generalization of the SBMI field as a whole incorporating all aspects which make a business model part of the SBMI field. The SBMI field is being praised by literature praises for steering the user in maximising positive impact of the company, whilst being economically viable (Baldassarre et al., 2017; Geissdoerfer et al., 2018; Shakeel et al., 2020; Yang et al., 2017). Within Sustainable Business Model Innovation, there are several approaches and models used, such as Triple Bottom Line. Most of them use a similar framework (N. Bocken et al., 2013, 2019; Geissdoerfer et al., 2018). In this research report a

framework as suggested by Bocken et al. (2019) was used that combines all the common aspects to generalise the SBMI field into a proper framework. Utilising and analysing this framework will allow one to study the SBMI field as a whole. Another reason for utilising this generalised framework, is that in the paper by Bocken et al. (2019) they apply the framework to several startups; the same application this research report sought to analyse. However, they mostly analyse the startup from an outside perspective, while this research report shall try to implement their framework from an early stage as a business model.

Research has shown that the traditional business models are way less effective for startups to implement than for larger corporations. This is mainly due to the fact that startups cannot rely on their previous data or experience as a source of information as they do not have any (Bortolini et al., 2018; Teece, 2010). This would also suggest that the SBMI model might not be as relevant for startups as originally suggested. In order to research the applicability of the SBMI model on small startups, this research report shall analyse SBMI on the scale of a small startup.

Since it has been suggested that traditional business models and perhaps even SBMI might not be proper methods to analyse the situation of a startup, SBMI shall be compared to a less conventional business model (Bortolini et al., 2018; McGrath, 2010; Teece, 2010). The most frequently used business model in the startup world is the Lean Startup model, which is specifically focused on startups (Bortolini et al., 2018; Ries, 2011; Teece, 2010). It is a tried-and-true method in the startup world but is only slowly being accepted in the academic environment. The Lean Startup model focusses on an iterative cycle of build-measure-learn, where the startup rushes to get a minimal viable product and uses this to gather data on how to improve the product. It is relevant to note that the Lean model does not take sustainability as a main goal, but only as a factor adding value to the startup as a whole. To test if the SBMI model is sufficient or if it requires supplementary aspects of more practical models, it has been analysed how the Lean model would complement the SBMI model.

The main research question this research report shall therefore seek to answer is:

How can the flame retardant Kaumera material be implemented into commerce use using SBMI as a framework compared to the Lean Startup model from the perspective of a startup?

This question will be answered using the following sub-questions to analyse the framework given by the Sustainable Business Model Innovation and the Lean startup methodology:

- How does Kaumera work as a flame retardant and how effective is it?
- How can the SBMI method be implemented?
- How can the Lean Startup method be implemented?
- How to validate the assumptions in this research report and what strategies are feasible in the early stage, scaling and internationalisation stage?

1.2 - Boundaries and assumptions

To answer the research question, this research report will focus on one specific case. It will focus on the application of Kaumera as a flame retardant. The focus will be on the target customer being Small and Medium Enterprises (SME) where the client can apply the flame retardant after construction. To provide a flame retardant property to the material, Kaumera will be used in combination with other materials such as paint to provide a flame retardant property to the material.

This research report will solely on the previously mentioned application of Kaumera, but it would not sketch a complete picture without assessing the potential of other applications of Kaumera. Different applications of Kaumera have only been considered in the chapter *Scaling and diversification* since it has been assumed that in the initial phase of the business, there will be just one product.

Furthermore, the potential company shall not be considered the manufacturer of Kaumera, since there are already Kaumera producing facilities in the Netherlands with which the TU Delft has good relations and this Kaumera is a byproduct of the NEREDA® water purification method. These producers are therefore considered as separate parties which can reliably provide Kaumera.
This regional boundary also extends to the legal analysis. Since the main collaboration partners of Kaumera and Watermining are based in the Netherlands, it is assumed this business is to be based in the Netherlands.

Related to this is that our analysis will be company agnostic. The model should be universally implementable by any party fulfilling the assumptions made in this chapter. This would mean that a startup or spin-off would be able to found the proposed company, the producers of Kaumera could use it as an extra revenue source for their product, or a big company could found this startup. Since the financial and human resources that the companies that are connected to Kaumera have, are confidential, it would not be realistic to tailor the research report to one of these companies. Thereby, assuming the resources a startup has, this would make the research report more representative and more universally applicable. This means that no significant funds, cash flow or investments are assumed, in line with the vision of proposing an easily implementable startup.

The reason to analyse the application of Kaumera after construction, is that the legislation for building materials is very different from the legislation for flame retardants. If the flame retardant is incorporated into the material itself that is used in construction, the material as a whole is considered a building material. Therefore, the properties of the material before the flame retardant is applied is also relevant for legislation. Focussing on the application of Kaumera after construction allows the research report to focus on Kaumera itself instead of taking other materials into account, which would drastically widen the scope of the research report.

Furthermore, it has been assumed that in the period between the writing of this model and the launching of the product no major changes in the market, regulations and other dependencies occur.

Additionally, it will be assumed that smaller parties such as local governments and companies will not radically change their view on Kaumera or the resulting company between the validation and the launch. It has been considered that companies will accept or reject collaborations, sales or representations depending on the price and legislation. Since it was assumed the latter to remain constant, the first must be weighed heavily.

Lastly, it has been assumed that the parties that would validate the model and/or launch the company and product have no significant prior experiences or qualifications unless specifically mentioned.

1.3 - The market

Kaumera is a product from the NEREDA® wastewater treatment method. This means that Kaumera as a product is a resource obtained only from the waste. The usage of this product is therefore fully circular: waste is removed from cycle and made into a valuable product. Kaumera has a ten times lower carbon footprint than the materials it replaces (De Koning et al., 2023). Kaumera is additionally already proven to be have effective flame retardant properties and might therefore be an interesting flame retardant (Kim et al., 2020).

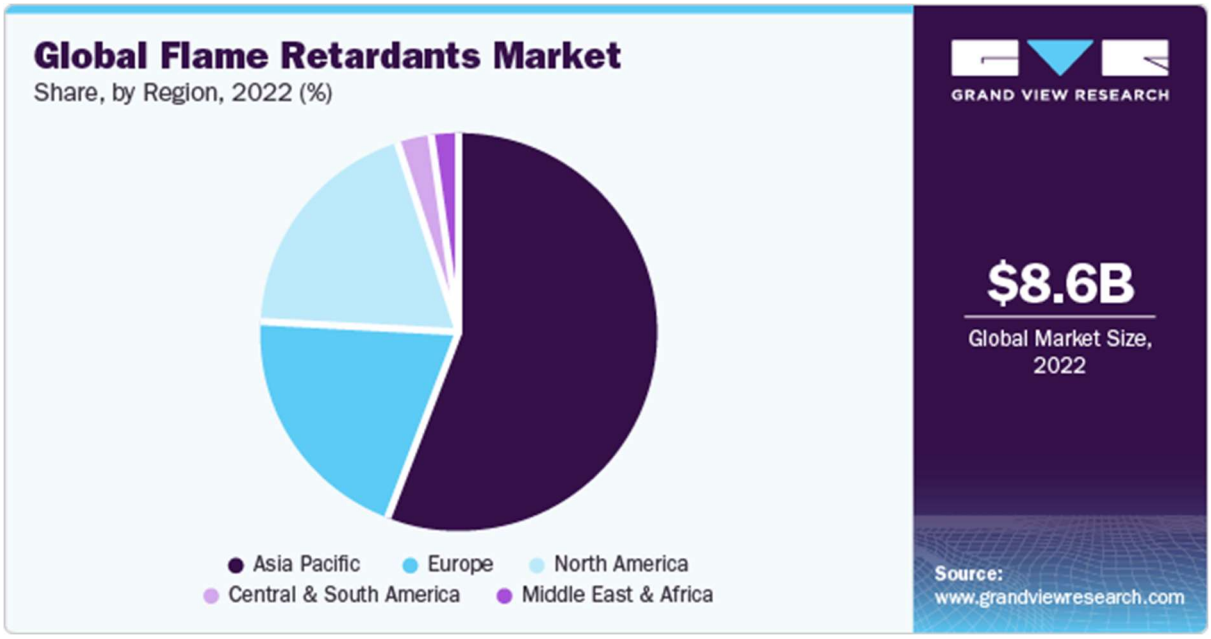

*Figure 1: Global Flame Retardant market (*Flame Retardant Market Size, Share & Growth Research report, 2030*, 2021)*

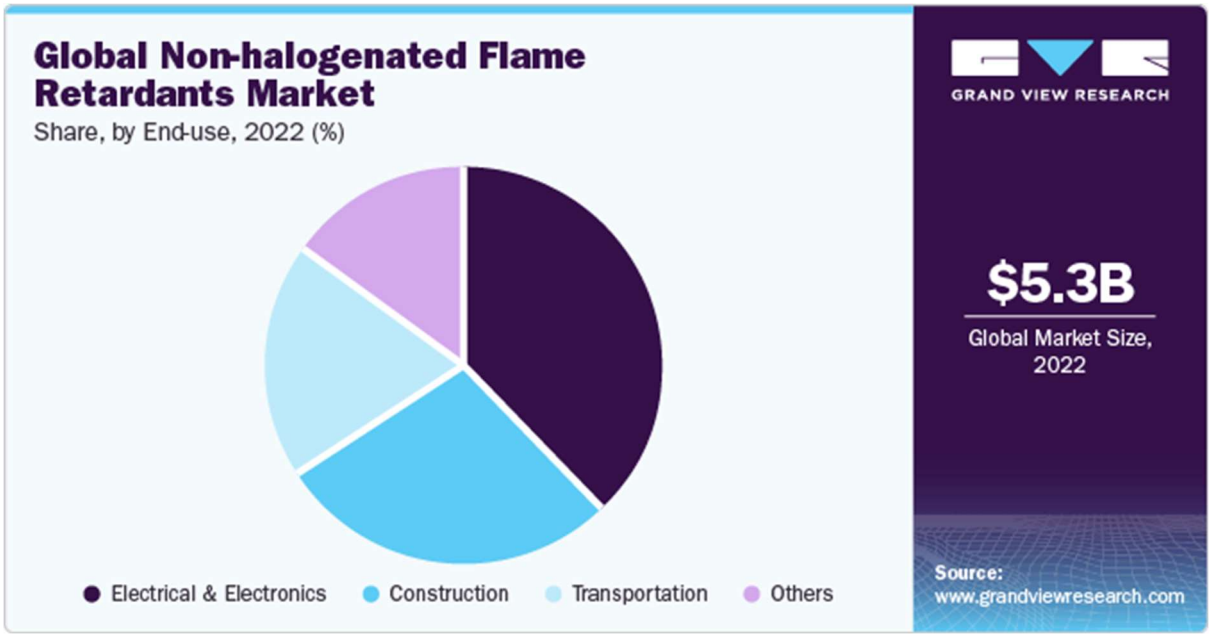

*Figure 2: Global non-halogenated Flame Retardant market (*Non-Halogenated Flame Retardants Market Size Research report 2030*, 2021)*

As is shown in Figure 1 and Figure 2, 61 % of the global flame retardant market is being supplied by non-halogenated flame retardants (European Chemicals Agency, 2023). This means that a non-halogenated flame retardants are not enough as a Unique Value Proposition (UVP). A UVP (also called USP for Unique Selling Point as it is more commonly referred to in the commercial world) is the added value a company offers to the customer, in which it is unique (Kambil et al., 1996). A UVP is often used to differentiate a company from their competitors and can be a major factor in why a company outcompetes its competitors.

Currently, flame retardants are being assessed by the European Chemical Agency, ECHA, to ensure that the new flame retardants replacing the old hazardous ones, are not hazardous as well. ECHA states that chlorinated flame retardants are still relatively common for the use in paints (European Chemicals Agency, 2023).

1.4 - Kaumera

Kaumera was initially defined as a alginate-like-polymer, where the main component was thought to be exopolysaccharides (Hogendoorn, 2013; Lin et al., 2010). These would not be suitable flame retardants since sugars are highly flammable. Later it was discovered that Kaumera also contains an abundance of amino acids, making it a glycoprotein (Espíndola et al., 2021). Proteins are more difficult to burn, and they lead to char formation. The fact that proteins are fundamentally less burnable than sugars, can be attributed to the existence of nitrogen as a base compound of amino acids, which is a known flame retardant in most forms. The fact that Kaumera is a combination of sugars and amino acids does make the precise analysis of Kaumera difficult. Kaumera is additionally known to contain certain phosphate and nitrogen compounds, as well as several different salts, which all serve as effective retardants.

As mentioned, the flame retardant would be produced using Kaumera made using the NEREDA®. NEREDA® is a wastewater treatment method that is an energy efficient alternative to standard methods. It uses aerobic granular biomass that solves the settling problem standard methods face. The biggest advantages are that NEREDA® has significant lower costs: it uses 50% less energy, uses up to 75% less land area and has an overall 25% lower costs compared to the conventional methods (Khan et al., 2015; Robertson et al., 2015; Strubbe et al., 2023). Because of this, it is likely that it will be implemented worldwide.

NEREDA® does not have to sacrifice its efficiency; it is as effective as stringent EU regulations require in purifying its waste stream, but also has the added benefit that it does not use any notable chemicals and can be scaled without requiring more vessel volume (Pronk et al., 2015).

Kaumera builds on this technology by processing the granular sludge that NEREDA® produces into usable resources to be used as building materials for other processes and to extract a significant part of the remaining carbon, nitrogen, and phosphorus. Kaumera is produced after processing the excess granular sludge from the NEREDA® process, as shown in figure 3.

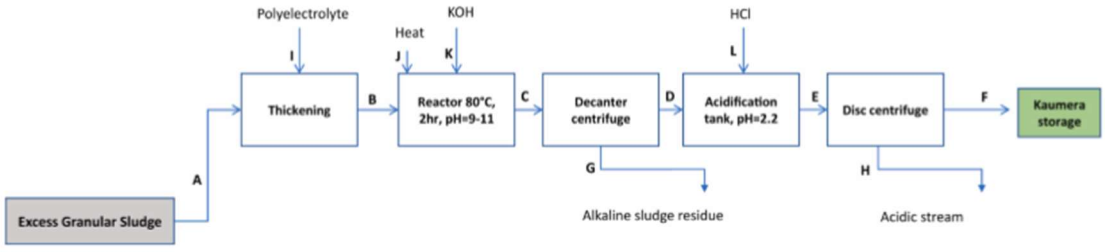

Figure 3: EPS extraction process from excess aerobic granular sludge (from Integrated resource recovery from aerobic granular sludge plants (Bahgat et al., 2023, figure 1)

The Kaumera production process reduces the sludge to a thickened sludge which after drying becomes a solid mass. This can be used as the building material which in literature is named an extracellular polymeric substance (EPS).

For the use as a flame retardant, Kaumera does not always need to be dried completely. Drying needs to be done if it is incorporated into the building material itself as a retardant, but the flame retardant Kaumera could be brought to public in its gel-like form, making it easy to apply to surfaces or to dip materials into it alike to how paint is being applied. This could make it easier to work with for small to medium sized companies which increase fire safety in existing buildings and would also cut down on the refining costs, thus making the material cheaper to produce.

1.5 - Mechanics of fire and flame retardants

Before one can delve into how Kaumera might be a sustainable flame retardant, a general understanding is needed on how fires work and how traditional flame retardants perform their function of slowing a fire. This will allow us to understand why Kaumera shows interesting properties as a flame retardant and what properties are thus important to maintain in the final product.

First, it's important to mention that the mechanisms of how fire work and therefore the mechanics of how retardants react with the fire are poorly understood. This holds true for most mechanisms related to fire and fire safety products, they have therefore been mostly determined empirically. This does not stop parties from developing new fire safety products, but this is rarely done from a theoretical perspective. This also means that legislation is made around empirical evidence that a product needs to conform to (Price et al., 2001).

The fire triangle is a commonly used method to explain the requirements of a fire, but this a simplification. The triangle names three requirements for fires and thus fire suppression: heat, oxygen and fuel. More accurate would be to describe it as a fire tetrahedron, since there are four components relevant for the existence of fire, as visualised in figure 4. The fourth component being propagation. This tetrahedron describes the components that make a fire and thus one or more of these components need to be removed for the fire to extinguish (Till & Coon, 2018).

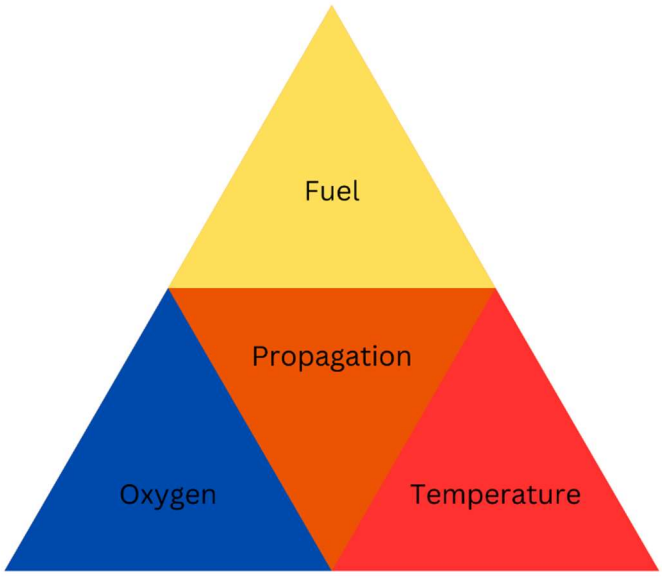

Figure 4: Fire tetrahedron depicting the three traditional aspects combined with the more technical aspect propagation.

Fire is a combustion, which, by definition, is an exothermic reaction requiring oxygen. Removing the oxygen, therefore stops the exothermic reaction and thus the fire.

To initiate a fire a certain temperature needs to be reached. The heat generated by the reaction of the fire allows the fire to maintain the ignition temperature that is required to perform the exothermic reaction, and thus it is self-propagating. By lowering the temperature, the fire is stopped twofold. Removing the heat that is created by the fire, prevents the fire from propagating by

removing the heat that is created by the fire, thereby preventing the ignition temperature from being reached by the next reaction. Furthermore, lowering the temperature slows chemical reactions, thereby making the propagation of the reaction slower.

Besides oxygen, fuel is required: this is often an organic compound that is reacting with oxygen, but can also be a metal or other energy rich compound such as ammonium compounds (Rogaume & Batiot, 2023). By removing the access to fuel additional exothermic reactions are prevented and thus the fire is stopped.

The last component, as mentioned, is the propagation. A fire is a chain reaction of radical molecules that radicalise other molecules such as oxygen and the stable fuel. This allows the fuel to become radical as well as the oxygen, which then combust, releasing more volatiles into the fire. This is a chain reaction, being propagated until either the fuel is gone, the oxygen is gone or the volatiles are captured. By capturing these volatiles, one can both extinguish the fire and minimalize the number of toxic compounds being generated (European Chemicals Agency, 2023).

1.5.1 - Types of fire

The fuel of fire is not exactly the same as the molecule being combusted. Solid materials as well as large carbon chains, such as oils, are quite stable yet they still burn. This is due to a process called pyrolysis. The volatiles of the fire strip a small part of a larger molecule as a radical, which due to its small size, becomes a gas. This gas radical can then react with oxygen to combust. Therefore, it is not wood itself that burns, but the components that are stripped from it, as is visualised in Figure 5. This adds an extra method of fire extinguishing: by increasing the distance between the fire and the fuel one both increases the heat dissipation as well as decreases the reaction speed of the fire. After all, if a molecule has to travel more, it is less likely to react. By increasing the distance between the pyrolysis, e the area where terminating molecules can catch the radical and terminate its propagation is also increased (*NEN Connect - ISO 3941:2007 En*, 2007; *NEN-EN 2 Brandklasse*, 1994).

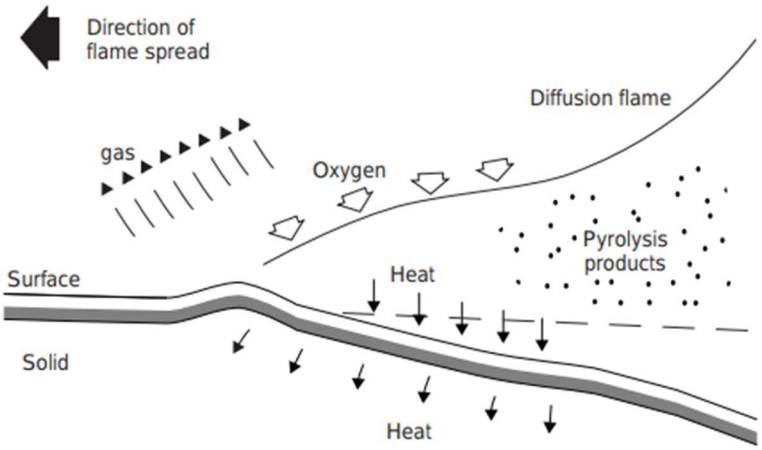

Figure 5: Visualization of a solid fire and the accompanying pyrolysis (Price et al., 2001, figure 1.5)

Solid fires are a common fire type; they are defined as "*fires involving solid materials, usually of an organic nature, in which combustion normally takes places with the formation of glowing embers*" (*NEN Connect - NEN-EN 2:1994 En*, 1994, p. 2) . This encompasses anything from plastic to woods and fibres. It is called an A-type fire (*NEN Connect - ISO 3941:2007 En*, 2007, p. 394; *NEN-EN 2 Brandklasse*, 1994).

B-type fires are fires involving liquids or liquefiable solids, such as gasoline or grease. Since grease fires are more common in residential or commercial environments, they are often given their own unofficial class, the F-type fire. However, they are officially still part of the B-type fires. As F-type fires are extra hot and hydrophobic, the extra classification is of added value. Extinguishment via water of F-type fires is highly dangerous since the water instantly evaporates due to the high heat and carries the burning fat molecules around the area. This often makes the fire propagate. This is an important difference to other B-type fires, as not all B-type fires are hydrophobic and the hydrophilic liquids can be extinguished using water-based solutions (*NEN Connect - ISO 3941:2007 En*, 2007; *NEN-EN 2 Brandklasse*, 1994).

C-type fires additionally burn using a gaseous fuel. A common example is a methane fire. C-type fires have a high expansion rate of gasses and a high concentration of oxygen around the gasses. This means that C-type fires have a high explosion danger (Jiang et al., 2013; *NEN Connect - ISO 3941:2007 En*, 2007; *NEN-EN 2 Brandklasse*, 1994).

Lastly, there are the D-type fires, where metals are involved. These can be the famous lithium fires of burning batteries, electric vehicles or other metals such as iron. Iron fires can occur in buildings when an exceedingly high temperature is reached. Due to the high temperatures of these fires, they are notoriously difficult to extinguish. One of the most common tactics is submerging the object in water. This does not extinguish the fire, but does prevent the fire from spreading; the fire will continue to burn until the metal is fully consumed (*NEN Connect - ISO 3941:2007 En*, 2007; *NEN-EN 2 Brandklasse*, 1994).

1.5.2 - Mechanisms of slowing or extinguishing fire

As mentioned previously, fires can be extinguished by removing one or more of the four components of the fire tetrahedron. Firstly they can be extinguished by removing the oxygen, which is frequently done by halogen extinguishers. This is often done in electricity dense environments such as computer servers. The advantage of the oxygen removal via halogen is that one does not damage the equipment since halogens are relatively inert and do not react with the equipment contrary to water. The disadvantage is that this method is lethal to humans in the room, since all oxygen is very rapidly removed and replaced with toxic gas (European Chemicals Agency, 2023).

A second method is lowering the temperature. This is often accomplished by dousing the flame in water. The evaporation of the water lowers the temperature. This method is used in large scale extinguishing, due to the low cost of water. Fire departments often use surface water due to its low cost and their high capacity of water transport. The disadvantage of water-based extinguishing is the previously mentioned damage that water can inflict. It will destroy water-sensitive materials, such as books and electronics and causes water damage to structures (European Chemicals Agency, 2023; Fryburg, 1950; Mawhinney et al., 1994).

Another temperature cooling method is the use of CO_2 extinguishers. These actively cool the fire by releasing compressed gas on the fire. Due to the rapid expansion of the gas, temperature is being

lowered. This method does minor damage besides the cold damage, making it excellent for environments like kitchens and factories, where one wants insignificant damage on materials around. But due to the cold damage, it is unusable against living creatures, since it will freeze them rapidly causing frostbite or death (European Chemicals Agency, 2023; Fryburg, 1950).

The third method is by terminating the chain reaction. Powder extinguishers uses salts that can capture volatiles. This way it can stop a fire from spreading, which is very much suited for A and B-type fires. The disadvantage of this method is the spreading of the powder. These powders are often highly corrosive to electrical equipment; since it can easily be carried on air currents due to its small size and will reach the circuitry where it will corrode the equipment (European Chemicals Agency, 2023; Fryburg, 1950).

Removing the fuel of the fire is rarely done, since transporting the burning object away from the fire is difficult to perform consistently. This method is used when one moves the burning candles away from the curtains, but there is not a method that performs this on a larger scale (European Chemicals Agency, 2023).

One can combine these methods which is done with foam extinguishers. Beside cooling the fire, it also forms a film over the fire, slowing the transport of pyrolyzed material and oxygen, slowing the chain reaction. This method is suitable for A-type fires and can be applied to living creatures to extinguish the fire affecting them (European Chemicals Agency, 2023).

Slowing and extinguishing fires is the same. If one slow a fire enough, it will extinguish. Yet these terms are used separately since extinguishing a fire is not always a viable option. Extinguishing is an active task, whilst slowing it can be passive. Slowing a fire could, for example, be achieved by the material properties. This is why flame retardants slow and self-extinguish: they allow the fire to slow to such a degree that it cannot sustain itself. Flame retardants are therefore materials that are applied before the fire, that passively slow the fire (European Chemicals Agency, 2023).

1.5.3 - State of flame retardants

Flame retardants are different from fire extinguishers as they make fires more difficult to start, to propagate and easier to be extinguished. They are often applied on materials that are inherently fire propagating such as organic polymers, for example, wood, cloth, and plastic. They are therefore frequently used to prevent or combat A type fires. Flame retardants often use the same powders as used in powder extinguishers and are either incorporated in the production of the material or applied afterwards. How flame retardants work mechanically is still poorly understood and thus flame retardants have historically been determined empirically (European Chemicals Agency, 2023; Price et al., 2001).

One remarkable flame retardant is char; just as powders or film forming materials, char covers the area between the oxygen and the fuel. This barrier slows the fire. Char is interesting because it is a result of the incomplete burning of the material that formed a carbon rich residue. This char formation in turn slows the fire. Evidence does indicate that phosphorus and ammonium are char-formation-stimulating compounds. Other char-forming compounds can be certain polymers. The combination of phosphorus and char-forming polymers is very effective but very hard to commercially produce (European Chemicals Agency, 2023; Maiti et al., n.d.; Price et al., 2001).

The mechanism of the process that forms char is debated in the literature. Properties that have been suggested to impact the char formation are polymer cross-linking, melt viscosity and the surface tension of the melt-gas interface (Price et al., 2001).

In some polymers metals are added both as a flame retardant and a smoke suppressor. The mechanisms of most of these retardants is poorly understood. One stated problem of this method is the reliability of metals (European Chemicals Agency, 2023; Fryburg, 1950; U.N. environment programme, 2017).

Another flame retarding method is using halogen compounds. Halogen based retardants are often used in synergy with other retarding methods such as metals or salts. The most important compound when looking at halogens is antimony, a crucial metal that synergises with halogens. The use of halogens is also a reason why polyvinyl chloride is considered inherently fire retarding. The disadvantage of PVC when exposed to fire, is that it releases toxic chlorine gas when burned. Halogen compounds are also the functioning compounds in PFAS, which gives it its flame retarding capabilities (European Chemicals Agency, 2023).

1.5.4 - Effectiveness as a flame retardant

The flame retarding properties of Kaumera were first published by Kim and his team (2020), in which the flame retardant properties were tested according to US Federal Aviation Regulation standards. Following that, they published in 2022 the characteristics of the char that forms after combustion and in 2023 they researched the flame retardancy of composites of Kaumera, specifically composite with natural fibres (Kim et al., 2020, 2022, 2023)

Kim et al. (2020) shows that the extracellular polymeric substances (EPS), such as EPSflocs and EPSgranules, were successfully extracted from activated and aerobic granular sludge, respectively, and tested as bio-based flame retardant materials. Flax fabric was coated by the biopolymeric substances and its flammability was evaluated based on a vertical burning test defined in US Federal Aviation Regulation. Both EPSflocs and EPSgranules coated flax fabrics achieved the self-extinguishment due to effective char formation. In particular, the result of the EPSgranules coated sample met the aviation requirements for the aircraft interior. Moreover, the presence of carbonated hydroxyapatite was identified in EPSgranules char residue by using FTIR and XRD analysis. It can contribute to the self-extinguishing property of the fabric by enhancing char formation. Thermogravimetric analysis also demonstrated that EPSgranules coated flax was able to produce greater amount of char residue and its decomposition rate was significantly reduced. This research indicates that there is a great potential to use this biopolymer as a resource for developing high performance bio-inspired flame retardant materials and contribute to a circular economy (Kim et al., 2020, 2022, 2023).

Some of these experiments were done conform to the ISO (International Organization for Standardization) standards. These are the guidelines for international harmonization, but they are not always the same standards as that region holds. One such case is the EU and her member states, which is why Kaumera is not officially proven to be an effective commercial flame retardant in the EU. Within the EU there is also an attempt to unify all the standards, so trade and movement within

the union is simplified. However, this is a lengthy process and member states still frequently hold their own standards which overrule both the EU and the ISO standards. Furthermore, the EU does not always take the ISO as their guideline. This is a difficulty in the worldwide harmonisation of standards.

This is also the case for the fire safety tests. ISO standards deviate from the EU and local standards often in small ways. One such example is the test from the paper from the 2020 where Kim and his team test a Kaumera composite according to ISO and international aviation standards. However, these standards deviate slightly from the norms that are required in Netherlands or other countries in the EU, as shown in NEN-EN-ISO 6940. Even though the deviation is how the flame is angled and the time duration that the flame is applied. This means that the performed test is NOT showing that the Kaumera conforms to the EU and Dutch legislation, but it is a strong indication that Kaumera is an effective commercial flame retardant and the test could be easily adapted to the proper method required by the NEN standard.

1.6 - SBMI

Figure 6: visualisation of the SMBI values and approach. The outer circle represents the important aspects that influence the SMBI model, the middle circle represents the unique aspects and important distinctions of the SBMI model compared to other sustainable business models, the inner circle represents the company itself, being the centre of focus.

In order to research Kaumera and how effective the Sustainable Business Model Innovation model is for startups, research through design methodology (Joost et al., 2016; Stappers, 2012). Business models analyse the core concepts of the business, search for the strengths and weaknesses and allow for an academic conclusion on the viability of the business proposal. However, most of these models are focussed on the customer experience or the economic viability of the product for the medium to long term. This does means that the added value of sustainability is less highlighted (Baldassarre et al., 2017; N. Bocken et al., 2019; Geissdoerfer et al., 2018; Shakeel et al., 2020; Yang et al., 2017).

Sustainable Business Models is a field, using methods as Value Mapping Tool (N. Bocken et al., 2013), Triple Layer Business Model (Joyce & Paquin, 2016) and Flourishing business canvas (Upward, 2013) (Lüdeke-Freund & Dembek, 2017). Sustainable Business Model Innovation is a research stream within the Sustainable Business Model field.

According to Bocken et al. (2019) Sustainable Business Models have several problems. The first problem they mention is a lack of context regarding the business environment of analysed business. This concretely means that it is poorly agreed upon in literature what a business model is and that the model often does not focus on the bigger picture. Secondly, they state that boundaries are often poorly defined, so the impact of the business is badly delineated. This leads to the third point, where most models do not take the impact of the business on sustaining the bad practises into account; if the business' main selling point is using recycled materials, they need there to be waste streams for the business to perform their main activity. This would have the consequence that the business would still advocate for a shorter product cycle so they can maintain their selling point.

The Sustainable Business Model Innovation utilising the framework of Bocken et al. (2019) tries to reduce these problems by specifically looking at the possible impact the business might have, as represented by figure 6. This is done by defining which dependencies the business has, how they affect the company and how they affect the consumer. The core of this and other sustainable business models is to foster sustainable development by focussing on solutions with sustainability as a core value and reduce negative impacts on society, nature and the company in the long term (Geissdoerfer et al., 2018). Even though the model is made to be implemented in business generally and should be applied to all types of enterprises, the SBMI has been expected to be implemented mostly by sustainable businesses such as circular businesses, social enterprises, bottom of the pyramid businesses and product-service systems (Geissdoerfer et al., 2018). Since the business designed in this research report is circular, the SBMI should be applicable. The framework Bocken and her colleagues proposed (2019) combines all aspects of business models in the SBMI fields into one framework to generalise SBMI and make SBMI directly applicable. This framework is used in this research report since it allows us to analyse the field of SBMI as a whole.

Interestingly and something that sets it apart from other models or fields, is that for SBMI it is not needed to develop a new product, just to create new value or to capture new value. This can be from the added sustainability or from another channel (Yang et al., 2017). It adds value by creating a competitive advantage by creating more value to the customer (Lüdeke-Freund, 2010). This would make the SBMI in theory universally applicable as shown by the four types of SBMIs.

These are the SBM startups, which build something new with sustainable elements, the SBM modification, which change a business model with sustainable elements, SBM diversification, which keeps the business model the same, and adds some sustainable value, and last, SBM acquisition, where a company becomes more sustainable by integrating a sustainable company in its portfolio (Geissdoerfer et al., 2018). This would mean that theoretically SBMI is usable for all sizes of companies. This statement is critically analysed in this research report.

1.7 - Lean Startup Method

The Lean Startup method operates on a radically different foundation than conventional business models. A startup should be quick to adjust and adapt, whilst larger companies can afford to be more fixed on a specific approach. This is exactly, according to Lean, why startups benefit from a more agile approach and thus a business model focussed on this adaptability (Ries, 2011). The Lean movement became popular when Ries launched his book The Lean Startup in 2011, which although it did not use a rigorous scientific basis, still became a staple model to follow for startups (Bortolini et al., 2018; Ries, 2011). Due to the fact that the book itself uses very little literature as a basis nor specific sources in the scientific sense, it has been suggested that this is the primary reason why the Lean method was not embraced by the academic community (Bortolini et al., 2018). After the launch and the widespread embrace of the Lean method by the startup community and its adjacent sectors such as the investing community, there has been more literature written on the subject in an attempt to align the Lean method with the academic framework.
The Lean Startup method takes a lot of inspiration from the manufacturing method implemented by Toyota, called the Toyota Production System. This has later been generalised to the term Lean Manufacturing (Bortolini et al., 2018; Krafcik, 1988).

As mentioned before, the Lean method mostly builds on the concept of iterative development. The so called “Build-Measure-Learn” cycle incentives the entrepreneur to get data from the prospective user to adapt the product as quickly as possible to the wishes or needs of the user (Ries, 2011). This allows the user of the Lean model to ‘fall quickly’ and thus waste little time on development or research that do not contribute to the value of the product (Ries, 2011). This allows the user to generate more ideas on which to build the product, which to measure the data, from which they acquire data. This is what the Lean method is known for, but there are a couple more steps to model itself.

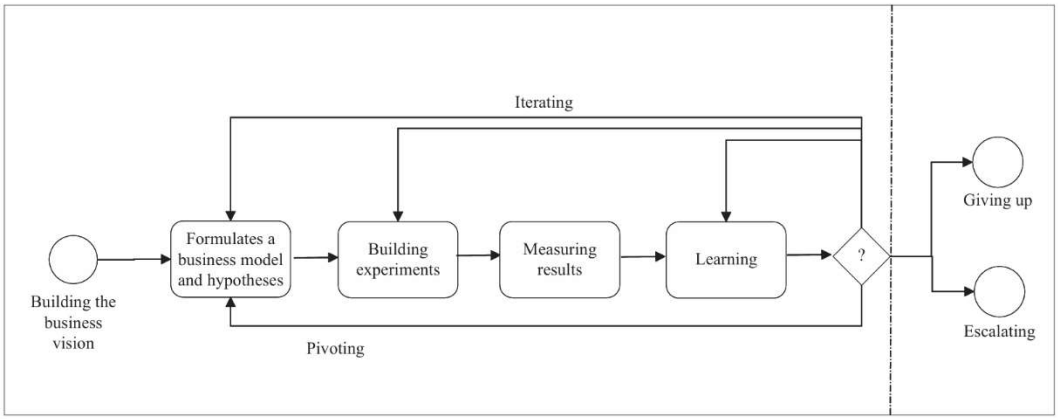

Figure 7: Representation of the Lean process (Bortolini et al., 2018, Figure 2)

The very first step in the Lean process is the building a vision. What are the core values and ideas on which the company is based. This includes a general idea of where the revenue should originate from, what value the company should add to society, and what type of product or service the company should provide.

This is used as a core foundation with which to enter the iterative cycle, as shown in Figure 7. This cycle starts with a business model and hypothesis, after which experiments are done and data is gathered to test the hypothesis and thus the model. This is done with the goal to optimize the product or service for market viability.

Since the testing of the hypothesis often does not require thorough testing or expensive prototypes, a minimal viable product is often enough to gather the data on the hypothesis. This allows the data to be gathered quickly and cheaply.

Since applying Lean and SBMI are not mutually exclusive, they can be compared by using them both, as per the philosophy of research through design. This gives valuable insight into SBMI, Lean, how they interact with each other, and what their flaws are.

2 - Materials and Methods

To analyse the potential of Kaumera on the market and to analyse how effective SBMI is as a model to describe this business model, two main methods were used as part of the research through design methodology.

This has been done in line with the generalised framework of SMBI as proposed by Bocken et al. (2019). First the parameters of the analysis have been defined as well as the aims of the company and how it affects sustainability (in the broadest sense of the word), and which dependencies the company would have. These include analyses of the market, producers, regulations and other influences on the product and business. Then it has been projected on how to increase the positive impact of Kaumera as a flame retardant and how to decrease the negative impacts it might have (such as the previously mentioned reliability on waste streams). This was finished by suggesting what the following steps would be to validate the model and product and how to scale the product sustainably by using the dependencies as an advantage.

To implement Lean, it is important to establish a proper business vision first of all. This is very much in line with the aspect of SBMI. Where Lean generally mostly focuses less on the business side, if the business where to take sustainability as its core foundation, this would be made clear in Lean business model as well.

Secondly, a business model and corresponding hypotheses must be constructed, which can be tested during the process. These should be tested cheaply and effectively, in line with the Lean method. For example, for the hypothesis “Kaumera can be produced at a price comparable to competing flame retardants”, data can be gathered by performing a market analysis. This allows the hypothesis to be quickly and easily confirmed or denied.

Since the SBMI framework is used as our main model, one has to construct and validate the hypothesis along the lines of the SBMI structure. A new hypothesis shall therefore be theorised per chapter and will at the end of the chapter be validated or rejected. The data shall be gathered using desk research or interviews and the data shall steer the research to new research questions. Since these hypotheses are not exactly the same as the research questions and their related hypotheses, they shall during the research report be indicated as Lean hypothesis.

Since Lean is a model based on incorporating data to form a new hypothesis quickly and based on the data acquired by validating the hypothesis tested before, it is not possible to formulate all of the hypotheses tested beforehand. This would be contrary to the Lean Startup Method. However, there are several core hypotheses that would need to be tested since they could be dealbreakers.

These core Lean hypotheses are:

1. Kaumera is an effective flame retardant.
2. Kaumera as a flame retardant can be sold on the market against a market conform price.
3. There is no legislation preventing Kaumera to be sold as a flame retardant.
4. The company can scale their business based on Kaumera.

If any of these hypotheses are rejected, it would be quite difficult to become market viable. All the Lean hypotheses suggested during the research report are to validate these four hypotheses.

These core hypotheses are answered according to the SBMI structure. If SBMI does not consider crucial aspects of a startup, which are generally considered to be vital or needed to answer the 4 Lean hypotheses, a separate chapter shall be written to formulate, test and validate a core hypothesis.

It is important to mention that the acceptance of a Lean hypothesis is separate from the hypotheses given as a part of the research question. These are part of the Lean methodology, which is applied in line with the research through design methodology.

Finally, a separate chapter (chapter 7) shall be written to learn from the data acquired and the hypotheses tested, to suggest further hypotheses and approaches to test these hypotheses in the short or mid-term if the company were to proceed. This is in line with the core Lean hypothesis 4.

The two main methods of gathering data have been a literature study to discover and list the required actions needed to launch a product on the market. These included steps such as a legislative and market analysis as well as scientific literature to verify assumptions made by legislative and professional parties. Research was conducted targeting the proposed hypotheses or conform to the SBMI framework (N. Bocken et al., 2019).

Secondly, semi-structured interviews were conducted with stakeholders and experts. These included parties that have showed interest in Kaumera via a grant application, as well as other experts in the field (Osseweijer, 2021). These interviews were used to systematically ask questions regarding their interests and experiences in the field and were used to verify statements made by scientific literature and legislative bodies as well as verify assumptions made regarding the market and the industry.

Not all interviews were able to be recorded due to privacy concerns, but all parties were given a one-week period to review the work and give objections to any statements made using the interview as a source. Interviews were made with commercial parties, fire safety experts and experts in academia as seen in Table 1.

Table 1: interviews conducted relating the company in which the interviewed individual works, their full name, the date of the interview and the expertise of said individual.

Company	**Individual**	**Date**	**Expertise**
Tanatex	Kolmschot, Sebastiaan	24-3-2024	Producer of textile coating – potential end user of Kaumera
H2K	Van de Graaff, Jochem	11-4-2024	Fire safety education facility
Saval – retired	Kimpe, Victor	9-1-2024	Retired director of fire extinguisher manufacturing
Brandweer & Biohazard Consultancy	Kerste, Rob	12-4-2024	Fire safety expert
Waterschap Rijn en Ijssel	Smit, Mark	9-10-2023	Kaumera producer

TU Delft	Picken, Stephen J.	30-1-2024	Professor polymer materials – researcher properties Kaumera

During the interview the following questions were asked:

1. Why are you interested in Kaumera as a flame retardant?
2. Why were you connected to the project to research Kaumera as a flame retardant?
3. What properties would be relevant for the flame retardant to have in your opinion?
4. Do you see a market for Kaumera as a flame retardant?
5. If a collaboration would be started, would you be a potential client or partner?

These questions led to questions and answers, which were used to validate or reject our proposed hypotheses or to strengthen the desk research already performed.

3 - Sustainability aims

SBMI requires the user to identify the changes the business wishes to implement into society and the market through its business. This allows the user to highlight the Unique Value Propositions (UVPs) of the product. Important to note is that a UVP does not need to be entirely unique if the company is unique when all UVPs are combined.
There has been several archetypes named in the SBMI field in which changes are categorised (Bocken et al., 2014, 2014). According to this framework, the change the company would initiate would mostly be categorised as the “Create value from waste” overlapping with the archetype of “Substitute with renewables and natural processes” (Bocken et al., 2014).

As mentioned before, two of the most commonly used and yet most problematic compounds are PFAS and halogens, as confirmed by Jochem van de Graaff, a professional educator in the fire safety industry (J. Van de Graaff, personal communication, 11 April 2024). Where the first compound’s main disadvantage is in its robustness and ability to bioaccumulate, the second has the ability to form toxic fumes such as chlorine gas. Now that these two compounds have garnered more public attention, there has been a movement to ban these compounds for all purposes except where it is irreplaceable. This change has been set in motion before and the prospective company would propagate this change; it is therefore not a fully unique selling point, but it is still an especially important UVP. Clients and governments institutions value this change highly (European Chemicals Agency, 2023; J. Van de Graaff, personal communication, 11 April 2024).

The second modification the company would seek to accomplish is the lack of circularity in fire safety and building materials as a whole (J. Van de Graaff, personal communication, 11 April 2024). Rarely are components being produced from waste streams. The only exception is the recycling of materials such as plastics, glass, wood, and rare materials. However, these rarely actually change shape and are often seen as inferior materials when looking at the material properties (Olsson, 2023). This therefore limits the application of recycled materials to mostly luxury items that do not need to perform any significant other tasks than its visual and texture aspect, for example seating chairs, public transportation seating and handbags. This method of recycling is called upcycling (upgrading and recycling) (Wegener, 2016). As mentioned, the application of upcycling and the market connected to it are quite small.
Due to the degradation of the materials, most materials that are being reduced are downcycled. This is done for more bulk applications such as recycled paper, glass and metal (OECD, 2019).

A second reason that circularity is rarely used, is the limited volume of high-quality waste streams. Most waste streams are a combination of a lot of materials and to purify this stream, an expensive process must be used. These extra costs make the price of the material higher than if the material was produced from virgin materials, thus the traditional source. (OECD, 2019; Olsson, 2023).

Remanufacturing within the EU is responsible for only 0.4 to 11.5 % of the resources used in industry. Only one industry, namely aerospace, has a market share higher than 3% in the remanufacturing market. Most of the materials recycled are metals, due to their high value and relatively low costs of separation and purification. Producing an excellent and economically viable flame retardant could significantly increase the market share of remanufacturing since flame retardants are used in many

industries - although the focus in this research report has been narrowed (Atasu et al., 2008; Bernard, 2011; OECD, 2019). This is very unique and thus a valuable UVP.

Furthermore, the best way to implement a new sustainable innovation is by lowering the barrier to entry by implementing the innovation into an existing need (Heidenreich & Kraemer, 2015). Therefore, the company should seek not to change customer behaviour, since it is shown that changing customer behaviour frequently does not have a positive impact on the implementation of an innovative technology or innovation. This means that to be successful and to allow the company to have a major positive impact on the environment, it is vital that the product the company sells, does not require any behaviour change with the customer.

4 - Dependencies

The SBMI framework of Bocken et al. (2019) builds on dependencies, being the relation the company has to other parties in the widest sense of the word. They are the core of any business operating in a society and are therefore important to name, to determine their potential or existing relation to the industry or company, and to determine how the company can use these relations to the benefit of itself and society.

Dependencies are defined as companies, institutions, groups of stakeholders, clients or other parties which inherently influence the company and its operations. This influence could be for the benefit of the company, such as its clients, where one or both parties benefit from the relation with the other party. The dependency could also be disadvantageous to one or both of the parties, such as competitors, which reduce the market for the company by taking part of this market for themselves. Furthermore, parties which might have an impact on the company, depending on expected approach of the company, are also considered. One such example would be parties with whom the company could work together in collaboration. Lastly, dependencies could feasibly change over time, but for this research report the focus mostly lies on the short-term effects of the dependency.

4.1 - Kaumera, the substance

Lean Hypothesis: Kaumera is an effective flame retardant.

The biggest dependency the company would have would be on Kaumera and its qualities. Its price, effectiveness as flame retardant, its consistency, its carbon footprint, its effects on the environment and its material properties are all vital to the use of the material. This is therefore vital for the company as well as its clients.

Kaumera is an extracellular polymeric substance (EPS) that is produced from waste streams and thus its precise composition is dependent on the substrate stream the facility is using. As Stephen Picken (2024) describes when interviewed, Kaumera obtained from different sewage-treating NEREDA® facilities are hardly different. Stephen Picken is a professor in polymer materials and has done research on the material properties of Kaumera. The differences between Kaumera samples obtained from different sewage-treating NEREDA® plants are found in the components that are found in trace amounts, like heavy metals. They might play a key role in choosing the facility, since heavy metals are bound to regulation, even in trace amounts. However, it should not affect the effectiveness of Kaumera as a flame retardant.

Relevant to mention is that, if there are trace amounts of components in the waste stream of which Kaumera is produced and these are likely in Kaumera. This means that legally the product would not be “free” of these products, just “low” in these components. This could for example mean that Kaumera would not be free of PFAS, but low in PFAS (J. Van de Graaff, personal communication, 11 April 2024). This would significantly impact its image for the clients, as is mentioned by Sebastiaan Kolmschot, a representative of Tanatex, which is an interested party and potential client of the company. Tanatex produces textile coatings and see potential in the application of Kaumera as a sustainable flame retardant coating (S. Kolmschot, personal communication, 24 March 2024).

A bigger difference is found, according to Picken, with industrial and brackish water. The composition of components is significantly different; these sources also affect the macro qualities of the Kaumera, such as its viscosity and thus its practicality. The Kaumera obtained from these facilities has less gel-like qualities, a lower viscosity. Whether the Kaumera from these sources is a less effective flame retardant, is yet to be analysed.

For the application as a flame retardant the solubility of Kaumera is very relevant, as is mentioned by Rob Kerste, a fire safety professional who has done research on Kaumera whilst working for the TU Delft (R. Kerste, personal communication, 12 April 2024; J. Van de Graaff, personal communication, 11 April 2024). After all, it is known that in damp conditions flame retardants that are salt based, have a tendency to secrete the salts due to the moist in the air (*NEN-EN 16755*, 2017, p. 16755). This results in flame retardancy lowering over time. There are even specific regulations such as NEN-EN 46755 (2017) focussing on this precise problem. According to Picken (2024) and his team, Kaumera can be dissolved (although not easily) in water when air dried. This would make it an excellent addition to paints. It would drastically increase the flame retardancy of the paint without compromising the function of the paint. According to Picken Kaumera can be well mixed with a paint without having a noticeable effect on the paint and its properties (S. J. Picken, personal communication, 30 January 2024).

This does mean that theoretically Kaumera incorporated into paint can have its flame-retardant properties lowered over time. It can be speculated that the decrease is much slower than with normal flame retardants. After all, the salts, phosphate and nitrogen are built into the polymer in the form of its proteins. So, it can be speculated that the salts might be excreted over time, but the phosphate and nitrogen will remain fixed. This would reduce the loss of effectivity.

Interestingly, after drying Kaumera between 60 ^{O}C and 100 ^{O}C it becomes extremely difficult to dissolve Kaumera. This is interesting when integrating Kaumera into or onto a material itself. This means that one can permanently attach Kaumera, when producing building materials using an oven, or when applying Kaumera on site using a heat gun. This would negate the possible loss of effectivity that occurs with normal flame retardants (S. J. Picken, personal communication, 30 January 2024). However, since building materials are not within the scope of this research report, this possibility shall not be pursued further.

Kaumera has been found to have an added value to paints as well. Due to Kaumeras circularity the paint might be more sustainable and could apply for the EU Ecolabel. This would improve the image of the product as well as add an extra UVP to the product (*Regulation (EC) No 66/2010 of the European Parliament and of the Council of 25 November 2009 on the EU Ecolabel*, 2009).

Certain properties are of particular interest for companies. Kolmschot mentioned that Tanatex would require a material that is without smell, does not discolour (when exposed to sunlight), and has little impact on the texture or the colour for the textile industry (S. Kolmschot, personal communication, 24 March 2024).

Lean hypothesis is validated.

4.2 - Dependency on production

Lean Hypothesis: Kaumera can be produced on a larger scale, which can be fulfilled by the company or their partners in the short to long term.

As mentioned before, the company would not be the producer of Kaumera itself. Kaumera would be purchased from wastewater treatment plants using the NEREDA® technology and thus producing Kaumera. As mentioned before, it is important what kind of water the treatment plant is treating (S. J. Picken, personal communication, 30 January 2024). Nearly all Kaumera used in research is nearly all produced from communal wastewater and there is a significant difference between this communal wastewater and other sources such as industrial wastewater and brackish wastewater. Initially, it would be most consistent to use only communal wastewater treatment plants and test the quality of the Kaumera between different producers, ensuring it conforms to the standard set. It would be possible to use Kaumera from different sources, but due to the difference in material properties, this would likely be a different product in the eyes of the law and thus require separate testing and certification. For the first phase of the company, it would be wise to use the producers using communal waste water such as the plant of Waterschap Rijn en IJssel.

According to Mark Smit, process technologist from Waterschap Rijn en Ijssel, Kaumera is produced on an industrial scale for 5 to 10 euros per kg of dry weight Kaumera. Since the research report is looking at Kaumera in its gel-like form, no additional costs have to be made to dry the Kaumera and since the concentration Kaumera is 8%wt this corresponds to a production price of 40 – 80 eurocents per liter (M. Smit, personal communication, 9 October 2023). For this research report, we shall assume 2-5 euro per liter of production costs, due to added costs of labour, transport and the fact that in the final product the concentration will likely be higher than 8 wt.%. It is important to state that this would be on the high end of production costs, it is likely that the true costs are lower. (M. Smit, personal communication, 9 October 2023).

It is foreseeable that other plants will be able to produce Kaumera, since new NEREDA® plants are being build, such as the recently opened plants by Waterschap Vallei en Veluwe in the Netherlands and Saint-Gilles-Croix-de-Vie in France. At this moment there are more than 100 NEREDA® plants in 22 countries and they are still being build (*100th Waste Treatment Plant Using TU Delft's Nereda Technology Built in Florida*, 2023; *Nereda Transforms the World of Wastewater Treatment with the 100th Plant*, 2023).

Kaumera is already used for multiple applications. The two most used applications are as bio stimulant and high-end fertilizer. Waterschap Rijn en IJssel have been selling Kaumera commercially for these applications for some time (M. Smit, personal communication, 9 October 2023).

As mentioned, it is not expected that the raw resource for Kaumera will be significantly limited. After all, this resource is human waste and 5-10 kg of dry Kaumera can be produced per person being served by the NEREDA® plant per year. This would mean that if the Netherlands was fully being serviced by NEREDA® plants, this would amount to 90 to 180 million kg of Kaumera being produced per year in the Netherlands alone (De Koning et al., 2023).

It would be advisable to perform quality control on each batch of Kaumera. Every batch will be slightly different in its composition. Ensuring the quality of the material can be done empirically, since fire safety is empirically focussed. One straightforward way to perform quality control, is by

performing a test like the small scale NEN/ISO tests like NEN-EN-ISO 6940. This does not require a lot of material and can easily be performed periodically or per batch. This quality control will be more relevant and elaborate when new Kaumera providers will be taken as supplier to establish the baseline of the provider.

Lean hypothesis is validated.

4.3 - Dependency on the market and the company's competitors

If there is one thing a company is reliant on, it is its financials. If the product is not economically feasible, it will be nearly impossible to ensure this product will succeed long term. This means that the production costs need to be analysed and how these compare to the competitors. It is therefore important to ensure their prices are around the same of the competitors (Davidson & Simonetto, 2005).

Lean Hypothesis: There are competitors that produce flame retardants, but none that fill the niche of full circularity at a market conform price.

As Victor Kimpe, a veteran of fire safety and retired director of an important fire extinguisher company Saval, states, the market of flame retardants and extinguishers is quite saturated and difficult to get into. It takes a new party in the market around 10 years to break even and thus even longer to turn a profit. PFAS-free and halogen-free solutions are being developed and produced a lot and thus that selling point has less value (V. Kimpe, personal communication, 9 January 2024). This means that if one wants to enter the flame retardant market, you'd need a UVP that is different from just being halogen-free. Circularity can be such a UVP. Flame retardant made from Kaumera would be fully circular, which can be used as its UVP (R. Kerste, personal communication, 12 April 2024; S. Kolmschot, personal communication, 24 March 2024).

As mentioned before, the Kaumera plant in the Netherlands can produce Kaumera for 2-5 euro/L for its gel-like form and 5-10 euros per kg in its dried form, the first of which would be the purchase price for the company. If one assumes a margin required of 50% production/purchase costs, the wholesale price would be between 4 and 8 euros per liter of flame retardant. We, furthermore, assume that this margin covers the costs of packaging and logistics. This margin should also pay for the overhead costs, but whether or not this is sufficient, depends on the scale (Fisher, 2011). In its dried form this would be 10-20 euros per kg.

To analyse the financial feasibility, a small market analysis has been performed (Table 2). Competitors, meaning other post-production flame retardants, have been analysed for price and other unique value propositions.

Table 2: paint with price/L from the internet. Notable is that DRI-ONE is a flame retardant paint but is given by wholesale price. It is to be expected that the more expensive flame retardant paints would be around this price in wholesale price.

Name	Price per liter [Euro / L]	Source
Global Paint Wall Primer	10.07	(*Global Paint Wall Primer Kopen? - Decoprof.Nl*, n.d.)
Spray on Thermal Barrier - DC315 Thermal Barrier Paint for Spray Foam	17.22	(*Spray on Thermal Barrier - DC315 Thermal Barrier Paint for Spray Foam (SPF) - 5 Gallons*, n.d.)
DRI-ONE	10.00	(Desert Research Institute, Inc., n.d.)
BanFire Intumescent Flame retardant Paint	13.22	(*BanFire Intumescent Fire Retardant Paint (Class A - ASTM E84)*, n.d.)
Fire Barrier Paint	18.00	(*Fire Barrier Paint | FlameOFF®*, n.d.)
Sherwin Williams Firetex 5090 Paint	14.51	(O'Shaughnessy, 2024)
PPG Wood Finishes PE627QO | Grondverf & Voorlak	14.7	(*PPG Wood Finishes PE627QO Bestellen? - Decoprof.Nl*, n.d.)
Dulux Quick Dry Satinwood Paint	27.6	(*Dulux Quick Dry Satinwood Paint 2.5L Wit*, n.d.)
Drybase Liquid Damp Proof Membrane - Liquid DPM Damp Proofing Paint	23.096	(*Drybase Vloeibaar Vochtbestendig Membraan (1 Liter, Zwart) - Vloeibare DPM Vochtbestendige Verf : Amazon.Nl: Klussen & Gereedschap*, n.d.)

The selling prices of most flame retardants are between 10 to 20 euros per liter (excluding taxes) as shown in Table 2. These are specifically the flame retardants that can or have been incorporated into paint and are water based. These are prices for the consumer, except for the DRI-ONE paint, which is sold at wholesale price. One can assume that production prices are less than half, since retailers often take at least 40% of the consumer's purchasing price as margin (Fisher, 2011). This means that the production prices of these retardants are at max 5-10 euros per liter. As the prices of non-flame retardant and flame retardant paints are around the same (see Table 2), it can be assumed that the price per liter of paint is the same as the price per liter of paint plus flame retardant.
As shown Kaumera seems to be at a market conform price range. It needs to be said that 50% margin is on the smaller side. However, since a high margin was already assumed in the section of production costs, this can be assumed to be acceptable.

Around 50% of people are willing to pay significantly more for sustainable products than they would pay for unsustainable products according to some research (Laroche et al., 2001). However, this is contradicted by data from interviews; Tanatex in their own research discovered that at this moment in time, people are not willing to pay extra for sustainability or circularity even though they are actively looking for circular products and have taken a significant interest in the LCA of products they purchase (S. Kolmschot, personal communication, 24 March 2024). This is confirmed by Jochem van de Graaff of H2K and Rob Kerste who mention that sustainability has become a very important point of research in the fire safety industry, mostly on the environmental impact of the product (R. Kerste, personal communication, 12 April 2024; J. Van de Graaff, personal communication, 11 April 2024).

This means that using the sustainability of Kaumera as UVP is a valid selling point. However, this is specifically the case for consumers and larger companies, whilst the company would sell their product to SMEs. The added value of Kaumera as a sustainable flame retardant would have to be conveyed by the SMEs. According to research the flame retardant market is expected to increase by 5% each year and was valued as 6.7 billion USD in 2021 (*Flame Retardant Market Size, Share & Growth Report, 2030*, 2021; *Non-Halogenated Flame Retardants Market Size Report 2030*, 2021). Furthermore, the market is fragmented; there are many different distributors that take the majority of the revenue. It is therefore a 'soft' market to introduce a new product to but also a less lucrative. Since there are many players, it would be hard for a new product in fire safety to take a large share of the revenue (J. Van de Graaff, personal communication, 11 April 2024). If this is desirable for sustainability reasons, it would have to be subsidized by the government to either increase its exposure or to undercut competitors in price. This research report would not advice trying to become the market leader using government support since it would give an unfair advantage against the privately owned small companies producing at this moment and would therefore hinder economic stability and innovation. If no government support is given, the product can still be financially feasible; it would require some extra margin for marketing and sales (such as demonstrations and trade fairs). If one assumes a budget of 100% production costs for marketing and sales to increase the hold on the market, the wholesale price would still be between 6 and 15 euros. This means that the product could turn out to be more expensive than its competitors. For the company to be economically viable, the company would have to maximally utilise it UVP using proper marketing and partnerships.

This is further confirmed by potential clients such as Tanatex, which would be absolutely interested in the material and prefer this material if it fulfils the conditions they set and is equal or cheaper than competitors (S. Kolmschot, personal communication, 24 March 2024). H2K confirms this conclusion, but adds that the fire safety industry right now is not focused on the sustainability of the production side, only on the environment side (J. Van de Graaff, personal communication, 11 April 2024).

Lean hypothesis is validated.

4.4 - EU, national and local regulations

Lean Hypothesis: There is no legislation preventing Kaumera to become a commercial flame retardant.

There are 3 tiers of legislation within the EU: EU level, national level and local. One problem is that legislation is not fully normalised. EU legislation is binding for all member states and its territories. If the EU bans the use of PFAS, all member states must implement this ban. However, a member state can still ban individual components, and this would be binding for that territory but not outside. This makes marketing and selling a product EU-wide more difficult. The company as a producer (which if one would launch the product with a new application, that party is a producer in the eyes of the law) would be liable for providing and complying with all the legislation. This might make international growth or collaborations more difficult.

Certain aspects of this EU-wide regulations are made to make trade easier. This especially applies to chemicals in the broadest sense of the word. As will be mentioned later, the MSDS and REACH are normalised, making it relatively easy to transport and sell. On the other hand, other legislation is area specific, such as waste disposal regulations and harmonized standards. One example are Dutch harmonization standards called NEN-EN. They are based on the European standard, but not exactly the same. This is particularly the case for fire safety protocols. Even though it is the aim of the EU to normalise these all over the EU, this is not yet the case.

Since flame retardants are required to have certification for specific applications, it is needed to look at every application at every region separately and perform the required tests. This makes region and application expansion more difficult (*Conformity Assessment – Ensure Your Products Comply with EU Rules*, n.d.).

The requirements for Kaumera as a flame retardant have been analysed within its specific application. This is highly relevant because without the analysis and certification, the product would not be allowed on the market. In addition, possible other certifications required for other applications shall be discussed. It will be restricted in all the analyses to the Netherlands, as set in the boundaries of the research report.

As mentioned before, for some subjects there are multiple standards for each level whilst for others it is just the EU level legislation. This is shown in Table 3, where different legislation at various levels is indicated by the presence of these legislation at different levels. This means that for these levels, the company would have to check the legislation for all these levels to find if there is no conflicting legislation.

Table 3: layers of legislation within the EU divided by EU-wide, national, and local legislation.

Category	EU	NATIONAL	LOCAL
Chemical safety during trade	MSDS		
Chemical safety in general	REACH		
Product harmonization	EN	NEN-EN	
End of life designation and proper disposal	End of Waste	End of Waste	
	Waste disposal	Waste disposal	Waste disposal
		Environmental regulations	Environmental regulations

4.4.1 - EU

The most relevant EU regulations are those pertaining to chemicals. Especially the bans are enforced EU-wide and the legislation pertaining to the storage, use, transport, and sale of chemicals is also enforced consistently. The most important institution regarding this is ECHA, the European Chemicals Agency. Its most important feature is the REACH database. Here all chemicals in the broadest sense are stored and published, open for anyone to analyse. They are actively researching and research reporting on different strategies for regulation on hazardous flame retardants (European Chemicals Agency, 2023). Keeping an eye on this would be vital for the company; they would have to comply, but they could also use this as promotion for their safe and circular product. Also, important to mention, is that REACH places responsibility for the chemicals with the producer as well as the burden of proof about the chemicals safety (*Understanding REACH - ECHA*, n.d.).

4.4.2 - National

The most important legislation that is done at the national level for this business, are the mentioned certifications. Since in our analysis the focus is on the Netherlands, the norms applicable are the NEN. As mentioned, these are specific to the Netherlands, but NEN-EN are EU harmonised. Again, this does not necessarily mean that the norm is valid in all EU countries, just that it is conform the EU standards.

4.4.3 - Local

Local, defined here as provincial and any smaller scale, legislation mostly does not introduce new systems. They mostly focus on environmental regulation and are thus only relevant for establishing a factory or working environment. Method of disposal of the material can also be regulated on local

level. These will not be discussed in detail since it is highly dependent on the exact location of the facilities.

4.4.4 - MSDS

There are several legislative requirements for a product to launch on the European market. The first and foremost requirement is a Material Safety Data Sheet (MSDS) (R. Kerste, personal communication, 12 April 2024). Every party can request the MSDS from the producer of the product. For scientific research, an MSDS is not required by law.
It is the fastest way to determine the dangers of the product and to clearly communicate these to other parties. An MSDS is necessary to bridge the gap between academia and commercial applications, it makes the substance much more accessible. Instead of just the big companies with their own research teams, the small companies can also use this product in the services. They do not have the resources to take the risk of investing in a substance that might or might not be allowed on the market.

The Waterschap Rijn en IJssel produced an MSDS sheet for their production of Kaumera. Interestingly it does not differentiate between the possible variants of Kaumera as 100% is defined as extracellular polymer substance. This means that for the intent of regulation, Kaumera with different compositions would be for all intents and purposes the same material. Furthermore, in the MSDS the dangers are indicated of Kaumera; these are mostly limited to the danger of explosion when exposed to heat for prolonged periods of time. This means that Kaumera is not a dangerous substance and does not need to be added to REACH's list of dangerous compounds. Since they are the producers of Kaumera, any client can request this MSDS sheet themselves.

If a different product is produced or a different manufacturer is used, a new MSDS sheet needs to be constructed. This is the responsibility of the producer; the company would have to construct an MSDS if it were to produce a product using Kaumera, such as a flame retardant paint, since the company would be the producer of that product.

As mentioned before, if a compound is not required to be on the REACH list and produced in significant amounts, it is considered safe. This of course is no guarantee that in the future it will also be automatically considered safe. It might therefore be wise to a toxicology analysis to verify that the thresholds and effects of Kaumera to reduce product liability for the producer and seller. After all, it is the responsibility of the business to ensure that their product is safe and the company has the burden of proof to show that the product is safe (*Understanding REACH - ECHA*, n.d.).

4.4.5 - End of waste

One crucial part of information is missing from the MSDS sheet, and this is an aspect that Waterschap has struggled with; the end-of-life information. Since Kaumera is technically a product produced from a final waste product, there is little legal precedent or opportunities to use wastewater products as new products. This means that the product would be legally changed to a product that is not a waste product anymore (called Einde-afvalfase or End-of-waste status) (Ivana, 2023).

The end-of-waste status can be given to a waste product to make it serve as a resource. This has been done for Kaumera as a bio stimulant and has recently been acquired for the waste material of the Kaumera process as a fertiliser in the Netherlands (M. Smit, personal communication, 9 October 2023).

The end-of-waste status can only be given to a product with a specific purpose. This would mean that one would have to reapply for the end-of-waste status. For this one would be able to keep most of the application the same, but one would have to change the use case.

For this the following data have to be given that are different from the bio stimulant application: uses, processes applied, relevant legislation and existing quality assurance schemes (Institute for Prospective and Technological Studies, 2009, article 1.3.3).

The aspects that are required here, are the ones that are discussed in research report. Therefore, when attempting to commercialise Kaumera as a flame retardant and applying to a new end-of-waste status, one could request the end-of-waste application from Waterschap (contact person Mark Smit) and change the application by paraphrasing this document.

4.4.6 - Flame retardant

For the application of flame retardant there are several regulations that are required for Kaumera to be named a flame retardant on EU and national level. After all, one needs to be able to prove that the flame retardant works.
As mentioned before, there has been some research done to the flame retarding properties of Kaumera. There is prove that Kaumera works as a flame retardant, but the tests would have to be redone according to prove their effectivity according to the EN and NEN-EN standards, along with all other tests that might be required for the territory to which the company would launch their product.

There are several other certifications Kaumera could apply for that would prove its efficiency and lower its product liability. These are not strictly necessary but would add value to the product. Some of these tests are only required for other applications such as a building material. This report will refer to these more in the chapter about *diversification of the applications of Kaumera*.

The first and most important test would be to adjust the tests done by Kim to make them in line with the Dutch regulatory standard, being NEN-EN-ISO 6940 (Kim et al., 2020, 2022). This test would be relatively low costs and easy to perform; requiring a fabric with Kaumera applied, a gas burner and a specimen holder, and some measuring devices.

Another ISO test that would be relevant for this test would be ISO 6941 for the measurement of the flame in this test and ISO 4880 for the definitions of the terms used in these tests.

The more resource intensive but very much advised test is NEN-EN 1363-1. This procedure describes general requirements of fire resistance tests. It can be used for a wide range of materials but does require a specific furnace.

Another test that might be valuable, would be NEN-EN 46755. This test compares the different situations in which wood is used as a building material. Specifically in dry, moist, and wet conditions, where flame retardants generally perform worse. It is known that many flame retardants release

some of the functional compounds, which are often salts. They are ‘secreted’ by the wood since they are easily dissolvable in water. Research has indicated that Kaumera is not easily dissolved after application, so this test would be perfect to verify this (S. J. Picken, personal communication, 30 January 2024).

Another interesting test when looking into the building material aspect is floors. For this NEN 1775 would be interesting to determine the aspect which floors contribute to the propagation of fire.

If developments and tests are required for the application of fire extinguisher, then there are several different tests to be performed.

ISO 7203 describes the standardisation of fire extinguishing media, specifically foam concentrates. These are useful in combination with ISO 7076 which describes the criteria the extinguisher itself must conform to. The Dutch standard relevant for fire foam would be NEN-EN 1568.

Lean hypothesis is conditionally accepted: if Kaumera performs the necessary tests, Kaumera can become a commercial flame retardant.

5 - Nature of dependencies

Lean hypothesis: there are several parties that would benefit from Kaumera becoming a commercial flame retardant with whom collaborations can be initiated.

The dependencies mentioned in the previous chapter are expected to influence the business in one of three ways according to SBMI: positive, negative, or neutral.
When the dependency is neutral, it means that the other party is not directly influenced by the business and/or the business is equally positively as negatively affected by the party.
When the business is mostly negatively affected by the company, such as the parties that benefit from the status quo, it is a competitive dependency.
When both the party and the business benefit from each other, the relationship is named symbiotic.

Table 4: Visualisation of the dependencies. Relation of dependencies to the business with one party given as example

Symbiotic	Neutral	Competitive
Kaumera producers – Waterschap Rijn en Ijssel	Legislation – NEN – EN related to flame retardants	Competitors - CLARIANT
Clients – Tanatex		
IP owners – TU Delft		
Academics involved with Kaumera – Yuemei Lin		
Potential partners – AMS		

5.1 - Neutrality

The only truly neutral dependency is the legislation. The legislation is there to protect consumers from faulty or risky products. This is particularly the case for fire safety products. It restricts flame retardants to products meeting certain requirements. This means that competitors that do not meet the requirements have a much harder time competing in the market, but it also means that new concepts such as certain applications or certain starting resources might not be yet accepted.

Fire safety regulations are made in collaboration with the industry (V. Kimpe, personal communication, 9 January 2024) and thus the biggest fire safety parties have the biggest impact on the legislation protecting them. This means that legislation could be a symbiotic relationship when considerable influence is reached. However, the business would be too small to reliably influence the legislation and thus would not be affecting the legislation. Since the legislation at this moment does not differentiate between very and less sustainable flame retardants, it cannot be used to increase the business's position on the market but the legislation in its state does protect the market and the business from ineffective flame retardants produced by competitors. This is vital since low quality competitors downgrade the trust of the clients in the market.

For legislation to turn into a symbiotic partner, the business would have to accumulate enough influence to steer the legislation to incorporate sustainability elements into the legislation. It seems that the ECHA and the EU legislative body is open to this as their documents indicate a strive towards sustainability and circularity, but their main focus at this moment is still the phasing out of dangerous and/or ineffective flame retardants (*ECHA Identifies Certain Brominated Flame Retardants as Candidates for Restriction*, 2023; European Chemicals Agency, 2023; European Commission, 2022).

5.2 - Competitive dependency

The biggest and most obvious parties that have a negative relation to the business would be direct and indirect competitors. Direct competitors that also sell fully sustainable and effective flame retardants would be fighting for the same niche in the larger ecosystem where the indirect competitors reside: the flame retardants market. Since people only purchase one flame retardant per application, every one of these parties are dependent on the others. After all, if someone purchases Kaumera, the competitor will lose a sale, and the other way around. Since the company would likely operate from a free market, this would mean that anyone could start a competing business even if the company would become a market leader. This would mean that both direct and indirect competitors would remain in a competitive dependency for as long as the company would remain on the market without a monopolistic position. Who the exact competitor would be, would be vary over time as companies get founded or go bankrupt, launch a new product, or retract their competing product, or pivot their business to another market or niche. It is therefore impossible to make an accurate prediction on who would be the competitors in the long term, only who would be a competitor in the short term. Examples of these competitors include the producers of the flame retardant paints in Table 2 or the market leaders of this moment (Albemarle Corporation, ICL, LANXESS, CLARIANT, Italmatch Chemicals S.p.A, Huber Engineered Materials, BASF SE, THOR, DSM, FRX Innovations, DuPont) (*Flame Retardant Market Size, Share & Growth Research report, 2030*, 2021; *Non-Halogenated Flame Retardants Market Size Research report 2030*, 2021). These companies offer both halogenated and non-halogenated flame retardants, meaning that they are indirect competitors. Some of them do offer circular non-halogenated flame retardant like CLARIANT (Clariant Ltd, n.d.) and Honext ('HONEXT® - Circular construction for a more sustainable world.', n.d.; Zeng et al., 2024).

This means that even within the market of circular flame retardants, Kaumera would not be the first nor would it be the biggest. However, circularity and the footprint of production are not main concerns of producers at this moment (J. Van de Graaff, personal communication, 11 April 2024).

5.3 - Symbiotic

The parties which benefit from the presence of the business on the market are the symbiotic dependencies. The most important one is the producer of the Kaumera substance. The NEREDA® plants which produce Kaumera can sell their product to the company. The more successful the company is, the more successful the plant is. This works primarily in an economic sense but also in a public relations angle. If the plants can sell their waste product as a secondary raw resource, they can profile themselves as more sustainable and thus more desirable. This could therefore lead them to acquire more orders of NEREDA® plants as wastewater treatment, increasing the businesses abundance of raw material. For the plant itself, it will mostly generate some extra revenue. One could argue that the different applications of Kaumera would compete for the same resource, but it is unlikely to happen. Kaumera is a byproduct of the NEREDA® process, which is built to fulfil a necessary function in society by the government and is therefore less reliant on the open market to be build. 85% of the waste water treatment worldwide is done by government institutions, such as the one by Waterschap Rijn en IJssel (Drechsel et al., 2015). This is shown by the fact that there are new NEREDA® plants being built without any significantly lucrative product being created from the byproduct Kaumera as there are more than 100 NEREDA® plants and the use of Kaumera is still relatively small (*Homepage - Royal HaskoningDHV*, n.d.). One therefore expects that the supply of Kaumera will remain exceeding the demand and that increased demand would only stimulate more plants being build and therefore more supply being delivered. After all, if a plant can sell some of its byproducts, the plant will cost the government less money.

The second party that has a symbiotic relationship is the client; also known as a good product market fit (Dennehy et al., 2016; Yarbrough et al., 2011). Besides being able to provide their customers with an effective flame retardant, they can also increase the sustainability of their clients. This gives our clients a sustainability edge but might also make their services applicable for subsidies and open new potential clients such as sustainability-focussed parties. This will help the companies clients generate clients and make their services more competitive as a result without increasing their costs. One such client could be Tanatex; they mentioned that these UVPs are very relevant for their clients and thus for them, whilst there is not yet an adequate offering (S. Kolmschot, personal communication, 24 March 2024). They would benefit from Kaumera as a product and thus have a symbiotic relationship with the business.

Thirdly, one of the most important dependencies are the mother companies. Specifically the institutions holding the IP for NEREDA® and Kaumera. If there is a company holding the IP preventing the use of Kaumera as a flame retardant by separate a party, a license for Kaumera would have to be purchased. Since the company is fully dependent on Kaumera, it is a requirement to have an agreement with the license holder. The party holding the IP, Royal HaskoningDHV Nederland B.V., could be a shareholder or have a licencing agreement; in both cases, it would benefit from the business being successful (Daniël et al., 2023).

On a related note, the academic world would also benefit from the business. Since the potential impact is an important factor for the editors in getting a paper published, the parties researching Kaumera and its properties would benefit from their results getting industrial usage and would boost their career (*Historical Development of the Journal Impact Factor and Its Relevance for Occupational*

Health, n.d.; Tijssen et al., 2000). This would particularly be the case if a patent was granted for this application (Tijssen et al., 2000).

Finally, one other symbiotic dependency that is not there yet, are collaborations and financing possibilities by other institutions. These can be collaborations with local, regional, national, or even international organizations such as county administration, government grants or collaborations, or fire departments. This allows the business to boost its reputation together with the said parties, generate sales, or acquire funding (Boydell & Rugkåsa, 2007). The other parties benefit from the dependency by creating positive publicity by increasing sustainability, increasing revenue, or making long term investments (Berawi, 2019). One such example would be a collaboration with Amsterdam Institute of Metropolitan Solutions (AMS) who have committed to full circularity by 2050 and thus Kaumera is of interest to them (Fabrique, n.d.; Osseweijer, 2021).

Lean hypothesis accepted.

6 - Increasing positive and reducing negative impact

In the section of increasing positive and reducing negative impact, the user of the SBMI shall anticipate on what the impact might be of their innovation on the short to long term. The reason SBMI dictates this analysis, is so the business is aware of the possible consequences of their actions and take responsibility for these consequences. This can be small possible changes in the behaviour of consumers to how the industry perceives the market. In turn, this prevents the business from causing unintended harm or allowing the business to utilise the potential changes it can cause for to the benefit of the company and society. Furthermore, this section is supposed to make the user or reader think about the possible unintended consequences, however unlikely they might be.

Lean Hypothesis: Kaumera would have a positive impact on society as a commercial flame retardant.

6.1 - Fire safety industry

The business would create an economically viable flame retardant that is effective and safe. This inherently captures and utilises the requirements of legislation and demands from customers for effective flame retardant. As flame retardants are an old concept and very well established, hardly any explanation is required to elaborate on the concept to the user or client.

The business stimulates the industry by pushing for and providing the most sustainable flame retardant. If the business can create enough traction within its target customer group as well as start collaborations with trustworthy groups, it can carve a niche for itself and other very sustainable flame retardants which leads to co-evolution of circular or sustainable fire safety industry (Janssen & Jager, 2002). By increasing the awareness of business, one also increase the pressure of the industry to go along with the changes and look for more sustainable alternatives (Janssen & Jager, 2002).

This can be shown by analysing LCAs. There is no LCA analysis comparing Kaumera to other flame retardants. However, this analysis has been published for when Kaumera is replacing alginate sources. Kaumera has a 8 to 45 times lower climate impact than its alternatives. One of these alternatives is the sustainable source of seaweed, which is already very sustainable with a low footprint and yet Kaumera has $1/8^{th}$ of the footprint of seaweed alginate (De Koning et al., 2023). Since the most sustainable competitor of Kaumera is Clariant's plant-based retardant, one can assume the same relation to the Kaumera and seaweed (Clariant Ltd, n.d.). One can therefore expect the footprint of Kaumera to be around a factor ten smaller than the most sustainable present competitors, making it highly interesting for parties such as Tanatex, where LCAs are becoming a larger part of their consideration. This would therefore give Kaumera a huge advantage on the sustainability aspect and push other flame retardant producers such as Clariant or Honext to reevaluate their UVP.

6.2 - Households and buildings

The business creates value for households as well. By providing a flame retardant with which people can reduce their footprint, one can fill a key role for climate conscious people as well as for people that have less interest in sustainability. For these people, the company provides even more value since one can convince these people that being sustainable does not have to mean compromises to comfort or financial impact (S. Kolmschot, personal communication, 24 March 2024).

Furthermore, parties responsible for construction would benefit from the sustainability promotion whilst not having to cut their margins or compromise on effectiveness, as is verified by Kolmschot (S. Kolmschot, personal communication, 24 March 2024). This is especially relevant due to the increasing pressure from politics to decrease the footprint of construction. This is an excellent way for these parties to significantly lower the footprint. After all, the footprint of this material could be considered negative, due to the carbon and nitrogen fixing aspects of the material's production as well as the comparative footprint of its competitors, especially the fossil-based competitors. However, more research is required for a more accurate statement on the footprint of the material.

6.3 - Production of circular materials

As mentioned, multiple times, the biggest Unique Value Proposition of the business would be the circularity of the Kaumera material. Validating the viability of fully circular materials will both increase the relevance of Kaumera as well as prove the economic viability of fully circular materials. This would then in turn stimulate both academic and businesses to invest in researching circular materials. This would greatly enhance their public image, since they actually take action using more sustainable materials, and if successful give them ownership over lucrative materials and processes (Janssen & Jager, 2002; Raska & Shaw, 2012).

As with any material, the resource it is made from are finite. However, since this material is made from human waste, its most important compound is practically infinite. It is highly unlikely that the demand for human or animal waste streams exceed the supply. At this point in time, the NEREDA® process produces 5-10 kg of dry Kaumera per person being served by the NEREDA® plant per year; meaning that if the entire population of eight billion people's waste would be purified by NEREDA®, this would produce 40-80 million metric tons of Kaumera per year. Meanwhile, the market of flame retardants is 2.39 million tons, a factor of 20 smaller than the theoretical production of Kaumera (European Chemicals Agency, 2023; European Commission, 2022). It is therefore highly unlikely that any shortage of Kaumera would persist long term.

One more benefit of increased value of waste streams, is that waste streams will be less likely to be discarded or burned as easily, since it creates more value when it is recycled or upcycled. This would mean a much more controlled waste stream flowing into nature, therefore problems such as eutrophication and water pollution (Brouillat, 2009; Ramayah et al., 2012; Raz & Souza, 2018; van Beukering et al., 2014).

6.4 - Brand building - Partners and subsidisation

As mentioned before, the parties involved with Kaumera already have a non-binding partnership with parties such as universities, water boards, and city governments. These are valuable relationships where both parties can benefit. For example, city governments might have sustainability targets such as the city of Amsterdam, where they have committed to circularity (Amsterdam, n.d.). This would mean that the business could work closely together with the city of Amsterdam to execute the early validation and launch. The city of Amsterdam would be able to connect with customers, be a customer themselves or even offer the opportunity for investment or subsidization. Secondly, the Waterboards are highly relevant. They are now and will remain in the future the main source of the material. By showing the benefits of the NEREDA® process and giving them an extra revenue source by selling the business the Kaumera, one would be able to incentivise further collaboration. Thirdly, the national and international government could be an excellent source of funding and collaboration to setup a network with customers and other parties. Subsidisation that might be relevant are WBSO (*WBSO*, 2015), MIT feasibility (*MIT-Haalbaarheidsstudie | RVO.nl | Rijksdienst*, n.d.) and MIT R&D (*MIT*, n.d.) for national level and international level using the action plan of the EU for increased circularity (COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Closing the Loop - An EU Action Plan for the Circular Economy, 2015).

Since circularity is a big topic on both local, national, and international level, acquiring partnerships should be beneficial for both parties.

6.5 - Potential spin-offs and other applications

One interesting application of Kaumera is as a composite. Kaumera can then be combined with other materials to give the other material more flame retardant properties or to enhance the flame retardant properties of Kaumera. Kaumera and its composites are known not to drip when melting (S. J. Picken, personal communication, 30 January 2024). Dripping is the effect of a burning material liquidizing and thus becoming extremely hot drops that can easily burn people. This is a vital quality for composites (Kim et al., 2020).

Composites with (nano)clay have been known to increase flame retardancy of polymers (polymer-clay composites). Due to the flammability of polymers, clay can be an advantageous addition (Kiliaris & Papaspyrides, 2010). There are disadvantages to the polymer-clay composites: it has been discovered that the composite does not slow down fully developed fires and it lowers the integrity of the polymer, lowering the ignition temperature (Dasari et al., 2007). This means that polymer-clay composites can not be considered fireproof.

For Kaumera, which is a glycoprotein, this might be different. Early research by Picken and his team indicated that the material is fully fireproof. In this composite, MMT is used as a clay. Sodium Montmorillonite (MMT), also known as nanoclay, bentonite, is a specific clay species which can form thin broad layers that are negatively charged. These can be combined with polymers, or in this case Kaumera, to form a labyrinth of layers intermingled with Kaumera. This material is impenetrable to oxygen, preventing oxidation and increasing heat dispersal, slowing pyrolysis. The early tests show huge fire retardancy potential. Furthermore, very little noxious fumes are released when burning Kaumera or the nanoclay, making it a relatively safe option (Dasari et al., 2007; DSouza et al., 2023; Guo et al., 2018; Kiliaris & Papaspyrides, 2010).

Important to notice is that this Kaumera-nanoclay composite is quite rigid. This would not allow Kaumera to be mixed with paint as an on-site flame retardant but would make the Kaumera-nanoclay composite an excellent building material for at risk areas. One such example is ceiling tiles, where the flame retardancy is important, but also rigidness of material. One don not want the tiles bending or breaking, but they also don not need to carry big loads (Dasari et al., 2007; DSouza et al., 2023; Guo et al., 2018; Kiliaris & Papaspyrides, 2010).

Circuitry composites are also an interesting application for Kaumera. A large part of the flame retardants is used for in circuitry, as shown in figure 2, so finding composite that can conduct, could make consumer electronics or the circuitry itself safer. Kaumera might be interesting for this. There are several disadvantages known regarding Kaumera and conducting materials, such as metals. The most important one is that the biopolymer in composites need to be free of salts. This is not the case with Kaumera and purifying it, is quite a complicated process due to its low solubility when dried. One option to still use Kaumera would be to aim for cable casings, which are generally made of polymers. A good circuitry casing has flame retardant properties or is a composite with a flame retardant. Kaumera can be promoted as the most sustainable option due to its circular production combined with good flame retardancy and mechanical properties. Examples include cable housing, computer cases, switchboard cases, or any other shell housing electronics and being at risks for fires (S. J. Picken, personal communication, 30 January 2024).

Finally, one could delve into the application of fire extinguishing foam. This has been suggested by Rob Kerste, a fire safety expert who has worked with Kaumera during its development. In early

experiments it has shown excellent robustness in fire safety with proper viscosity making it a promising candidate for the use in fire extinguishers as a stabilising agent in the fire foams (R. Kerste, personal communication, 12 April 2024). Much extra research would have to be done to allow it to be used as a substitute for the existing foams, but this would allow a more efficient and fast implementation within the industry (R. Kerste, personal communication, 12 April 2024; J. Van de Graaff, personal communication, 11 April 2024). This would open up a whole new market, which is highly competitive, so it could be lucrative but would not be easily accomplished.

Lean hypothesis can not be accepted without further data.

7 – Future hypotheses, their measurements and consequences

As mentioned before, in line with the Lean startup method, the startup should always strive to verify new hypotheses. As this project is limited to desk research and interviews, certain hypotheses and their validation are outside the scope of this research report. Therefore, hypotheses shall be suggested to be verified in the further stages of the company.

Table 4: Visualization of the future steps for the three expected phases. It summarizes the discussed future steps and categorises them. Overlapping steps, being legal approval and subsidies are recurring since they are applicable to all steps. Product-market fit validation is required for each new product, so for early stage and diversification.

Category	Early- stage	Scaling and diversification	Internationalisation
Product-market fit validation	Bottoms-up product-market fit	Bottoms-up product-market fit	
	Top-down product-market fit	Top-down product-market fit	
Legal approval	Legal approval	Legal approval	Legal approval
Subsidisation	Subsidies	Subsidies	Subsidies
Increase production		Scaling production	
Increase market		Product diversification	
Decreasing costs / Increasing margin		Material diversification	
		Production plant production	
Market expansion			Licencing
			Branch offices
			Joint ventures

7.1 - Short term hypotheses and company development

Validation of the assumptions made in the research report are vital for the viability of the business. Especially regarding the market. The best way to gather this information is by getting presales from the potential customers before producing the first big batches or if producing is not a problem, already selling the product to these clients; this is the method the Lean model advises (Bortolini et al., 2018; Dennehy et al., 2016; Eisenmann et al., 2017). At this point the most relevant question is whether there is actual demand for the product, the latest hypothesis before a go or no-go decision would be "*There is demand for the commercial flame retardant Kaumera*".

There are two main avenues to contact potential clients to validate the hypothesis. Both require increasing awareness of the product to potential clients.

The most common and most stable method to increase awareness is by participating in trade fairs. This is a bottoms-up method; one convinces the person that would use it on the work floor to use it. Here companies show their product or service to the relevant industry. Some Dutch trade fairs that might be relevant are: FireSafety & Security (*Hét event voor beveiligend Nederland!*, n.d.), Worksafe (*Worksafe Gorinchem | 13 en 14 mei 2025*, n.d.) and facilitair beurs (*Vakbeurs Facilitair & Gebouwbeheer*, n.d.). The first two focus more on (fire) safety solutions so are near obligatory for the business. The third one focuses more on building managers so could be relevant to acquire larger customers. Possible other trade fair sectors could be the chemical trade fairs (for partners in industry such as Tanatex), sustainability trade fairs, or paint or coating trade fairs.

The second method would be to use the more top-down approach, where one convinces the higher-ups to use their product by using bigger channels or a network. To fully utilise this method, it is vital to get an introduction to the relevant party. One method to facilitate this, is by using the sustainability aspect to focus the managers. By collaborating with parties such as the city of Amsterdam or universities one can build their credibility and increase exposure of the business. This method also fits with the Lean strategy since one involves their possible clients in the process of determining the product-market fit. It allows the company to quickly and effectively gather data on how desired their product would be, the optimal asking price, and at the same time already build their network of potential clients (Bortolini et al., 2018; Dennehy et al., 2016; Eisenmann et al., 2017).

The advantage of the first method is the relative ease. It is easy to book a stand and promote their product, acquiring a few customers. It does require a minor investment of money and time, since most parties need to see the business exhibit multiple times at the trade fair or conference before approaching them.

The advantage of the second method is the high value of the approach and the speed with which the customer can be acquired. With the top down approach, one prevents having to climb the corporate ladder to get approval from the board. The disadvantage of this approach is that it can be hit or miss. One needs an introduction or be connected to the executive staff to arrange a meeting. This would be more feasible with this business, due to the large network of the partners and potential partners. The advantage of this method as the Lean methodology describes, is that the company quickly knows if and which of their assumptions are correct and one can integrate this feedback into their

product offering. This allows the company to quickly revise their assumptions and adjust their product to fit this new data (Bortolini et al., 2018; Dennehy et al., 2016; Eisenmann et al., 2017).

After acquiring some clients, the company can use these to gather feedback on the product, its pricing, its unique selling points, and potential new products. After all, it might be that the feedback from the clients strongly suggests that one should use a different application than the one described in this research report. Then the company could integrate this feedback for a new or adjusted product. This allows one to rapidly iterate the design as per the Lean methodology.

Legal approval

After the initial feedback and integrating this feedback, the next step is to finalise the legal approval of the product. This would mean getting the end-of-waste status for the application as well as finalise the certifications required or advised as described in the 1.5.4 – Effectiveness as a flame retardant section. It is advised to finalise the certifications with a party specialised on performing fire test, such as Effects B.V. They have the facilities to perform all the tests and are highly accredited, something which is vital for a starting business in fire safety.

Subsidies

There are several loans, grants and other forms of subsidization that can be used for starting a business. These range from loans to fund the early expenses, to the previously mentioned WBSO and MIT subsidy to fund research. These forms of funds can be acquired earlier in the validation process if needed and are often sector agnostic. There are also opportunities such as pilots specifically targeted at circularity such as Subsidie Circulaire ketenprojecten (*Subsidie Circulaire ketenprojecten*, 2020) or DEI+: Circulaire economie (*DEI+*, 2019). This last one is highly interesting since it focusses on the reuse or recycling of waste and production of biobased materials. This grant had funds available for the period of 2022 a of nineteen million euros and targets exactly this business. However, the grant is temporally closed. Other DEI subsidies might still be applicable such as DEI+: Energie- en klimaatinnovaties (*Demonstratie Energie- en Klimaatinnovatie (DEI+)*, 2023). This subsidy is broader but has a much higher total budget of 141 million with a maximum per project of thirty million euros. This could fully fund the validation phase.

There are also more local subsidies that cities or provinces may grant when circularity is a big part of the business. One such subsidy is small scale circular activity (*Circulaire regelingen (CE)*, n.d.), these are much smaller scale, with a maximum of 20.000 euro per project. The main provincial subsidies are still MIT and WBSO.

This would be the point in the Lean methodology where the startup would decide on their go or no-go. After the validation of this hypothesis, the company could make their go or no-go decision and launch the startup. However, finalising the no or no-go is not the end of the Lean Methodology or its suggested process. This is only a Minimal Viable Product and commercialisation is not the end of the Lean Startup methodology. This methodology will continue up until no development is done. A good business model looks further into the future, as is suggested by the Lean methodology. Therefore,

this research report shall describe some of the potential further steps, their hypotheses and the application of these hypotheses.

7.2 - Scaling and diversification

Lean hypothesis: the company and its product is scalable outside of the local market or by product diversification.

After becoming established on the market and not being reliant on subsidies anymore, it would be wise to look into the possibilities of scaling. There are two paths that maintain the core values that the business seeks to implement, whilst also being able to increase its reach (Davidson & Simonetto, 2005; Jha et al., 2021; Loukopoulos & Papadimitriou, 2022).

One could scale production with the existing products, or the business could diversify its offering.

Product diversification is the process where a company produces more products with the intent of generating separate sources of revenue. This is mostly done for three reasons: if the main business model or product is stagnating in growth, if the business wants to spread its risk so a sudden decline in sales would not endanger the company, or to increase competitive pressure by launching a product working on a hype, a successful competitor or a change in legislation. It would be advisory to initially remain in the niche that Kaumera would occupy initially, so circular fire safety, since research has shown that this is where the most success is accomplished by diversifying startups. Examples of this product diversification could be developing a composite with Kaumera or produce a flame retardant for circuitry with Kaumera. Possible other diversifications are using different sources besides just Kaumera and using the same or a different application (Jha et al., 2021). Most of the other possible applications of Kaumera have been discussed in 4.1 – Kaumera, the substance. The possible applications of the Kaumera substance that are discussed are still mostly within the fire safety field.

Scaling production might be necessary anyhow and can be achieved through two methods: building dedicated Kaumera plants by the business or facilitating the production partners to scale.

There are several advantages and disadvantages for both pathways. Firstly, building their own plants makes the company independent of other parties and gives a steady stream of product. This means the business would be less reliant on other parties and their supply. After all, even if the relations are positive at the beginning, they might sour over the years or the supply of Kaumera that they can supply might lower due to a higher demand elsewhere. However, building their own plant requires a lot of time, money, and expertise. Building a plant brings significant risks. Secondly, even if the businesses margins can rise substantially, their fixed costs will also significantly increase. This means that the business would be even more reliant on its sales and has therefore more operational risks (Barnes, 2001; *Designing Global Strategies*, n.d.; Dunert & Westerling, 2010).

The most likely route to success would be to initially focus on mutual growth and after reaching a size where the lost margins outweigh the risk of the plant, it would be wise to start constructing their own plants.

The risk of plants is minimised by the fact that the core facility is inherently adding value by treating wastewater streams. Therefore, the company might be able to arrange a collaboration with regional responsible parties without sufficient wastewater treatment plants to construct plants there. The region would pay for the treatment of the waste water and the resulting Kaumera can therefore be sold as businesses main product (Barnes, 2001; *Designing Global Strategies*, n.d.; Dunert & Westerling, 2010).

Another avenue to pursue would be to remain with the existing client base and look for alternative materials to produce the flame retardant with. After all, it might be that there is a material or production process that produces a flame retardant for half of the price, whilst still being safe and produced from wastewater with a more efficient process.

7.3 - Internationalisation

The last step would be to expand the business internationally. This step does not necessarily need to be after the scaling or diversification and can be implemented before the scaling or before diversification is finished or even started. The main big obstacle with internationalisation is the decrease of network and authority that the home market brings. Abroad the network of the partners and the authority of these partners will be less relevant. This means that starting in these markets the company has to start again with the building of networks, partners and clients. It is likely that the production side is not the problem since either the production from the home market is sufficient or the wastewater plant can be implemented on its own merits, specifically its efficiency in the wastewater treatment.

Two different paths are expected to allow the business to scale internationally. The most straightforward approach would be to open branch offices abroad. This involves replicating the strategies employed in earlier steps in different countries after a thorough analysis of each country. The process would include renting office space, hiring staff members, and establishing the necessary legal and financial groundwork. The disadvantage of this strategy is that it is quite cost-intensive and carries considerable risk, requiring significant funds. However, the major advantage is control. The business remains fully in control and therefore retains the highest margins. It allows for scaling as needed, and quick pivots remain feasible. The transparency between the offices enables the business to benefit from optimizations in one country and quickly implement them in others. The significant disadvantage is the high cost. External funding would need to be acquired, or the home market must be large enough to cover the startup costs of new offices. Additionally, there is no guarantee that the strategies effective in the home market will work in the new country. Cultural differences pose one of the biggest obstacles in international expansion. Interestingly, this method of expansion tends to slow down as more countries are covered. This means that while initial growth may be relatively fast, it tends to decrease in the later stages (Hutzschenreuter et al., 2011).

There is another pathway that is less reliant on labour or investment and relies more on partnerships: a licencing agreement. Here the company would give a party the authority to sell their product or use their technology using their brand. This would mean that the company would sell a license to local parties, which can be an upfront cost or a percentage of revenue. This partnership could be with multiple small parties (where they would be the intermediary) or more likely a larger party that performs the distribution as well. There are two main advantages of this strategy; there is not much upfront investment needed and the network of the licensee can be utilised. Since it is low startup costs, the business would be able to expand faster. It is possible to begin a deal like this before breaking even in the home market. This would give the business an extra revenue stream without much investment. The network of the partner also would allow the business to establish a solid foothold in the market quicker than would be likely when setting up a new office.

The main disadvantage of this technique is that the company would lose autonomy. There would be less control on the growth or lower margins. The business would lose much more margin than if a branch office were opened. Secondly, the large party that would be the partner would try to negotiate for exclusivity within their region. This would limit the businesses partners to just this licensee, but not allow the business to compete the licensees to perform better. The monopoly this would create, would not necessarily be bad for the licensor though, as the licensee could use the

position to up the price of the product as high as feasible, which could increase the margins (Aulakh et al., 2013).

There are a few options that lie between these extremes, the most interesting of which is the option of a joint venture. A joint venture would combine the benefits of the branch office in its transparency and utilization of the benefits of the home market with the network and capacity of the partnership that would occur with a licence option. Both parties would only benefit if the other also upholds their part of the deal, leading to a more uncertain but more trust-based relation. Both parties have just as much to lose if the partnership does not go well and just as much to gain from a good partnership. This option is combinable with the branch office route and even the license route, since the joint venture is ultimately a collaboration between the parties involved and is quite flexible in its execution. This would therefore be a very viable option to strive for (Inkpen & Li, 1999). One type of potential partner to collaborate with would be the competitors. Since this industry is very competitive, it would be beneficial to collaborate with larger parties which could use the product in their products or supply the product to their network (R. Kerste, personal communication, 12 April 2024; J. Van de Graaff, personal communication, 11 April 2024). Having one of the strategies in a certain region does not exclude other strategies in different regions. With the joint venture and exclusive license agreements the business would have to commit to that strategy for that region, but these contracts are often for specific regions.

Lean hypothesis can not be confirmed without further market research.

8 - Discussion

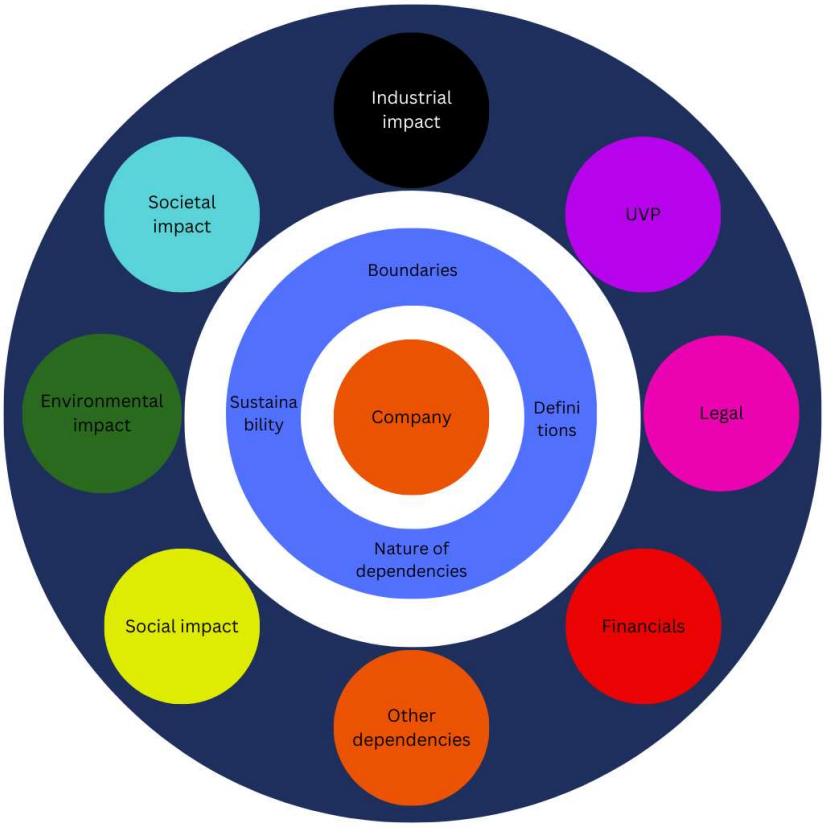

Figure 6: visualisation of the SMBI values and approach. The outer circle represents the important aspects that influence the SMBI model, the middle circle represents the unique aspects and important distinctions of the SBMI model compared to other sustainable business models, the inner circle represents the company itself, being the centre of focus.

The main advantage of SBMI is that this field increases the focus of sustainability and stimulates the user to consider all aspects of sustainability: short term and long term, and environmental, societal, and economic. This forces the user to consider potential effects that the business might result in facets that normally (and thus legally) would not be considered the result of the businesses actions. This strengthens the positive impact of the company, but also allows the company to use these impacts to further its public image.

SBMI also looks at the entire production chain to consider everything from the raw resource to disposal. Certain processes might seem sustainable by using biological material as a resource, but the process to get the resource to be valuable might be unsustainable. As it can be quite impactful, this also can strengthen the public image of the company and improve its sustainability. In this case, it was less relevant since the chain is quite short; it starts with an end-waste product and transforms this in a useful product utilising a small amount of relatively unimpactful processes.

All of these advantages are absent in Lean startup model unless the company really focusses on the sustainability aspects. If a startup considers using this SBMI framework, this will generally be the case, since sustainability is considered a core value of the company. For startups, that are less focussed on sustainability, Lean would not encourage the companies to look at the positive impacts their actions can bring. As mentioned before, these positive actions can be valuable selling points of

their services or products. This does not mean that Lean is lacking in this aspect, since it mostly focusses on getting a startup to produce value as quickly as possible.

A big focus of the SBMI field is the potential effect the company might have on business and consumer behaviour. It requires the user to think about what possible effects the company would have on usage. One example: if Kaumera uses waste streams and it becomes valuable, would that incentivize people to create more wastewater, since it creates more value? This assumes that one such company can easily affect consumer behaviour, whilst literature shows that consumers are less likely to accept an innovation if it is paired with changing behaviour. The consumer is often actively pushing back against innovations that require them to change their behaviour, like having to recycle or digital banking. This also leads to the fact that companies launching a product or service that requires a change the consumer's behaviour are less likely to succeed (Heidenreich & Kraemer, 2015). Since a company needs to consider this, when conforming to the SBMI field, this lowers the potential products or services it can offer. For example, SBMI does criticise products that are reliant on waste streams since the company would be dependent on the waste being produced. It would therefore have significant interest in maintaining this status quo. This creates a division between the SBMI vision and the data that research provided: the SBMI field inherently pushes the company to develop a product or service that breaks the status quo to change society for the better, but companies are much less likely to succeed in their vision if they pursue the change of the user. This would therefore lower the potential long-term impact of company. After all, if a company can not support itself, it can not continue to make a positive impact.

This highlights the advantage of the Lean startup model. This model focusses on what behaviour the user or consumer shows and directly investigates how willing they are to change. If constructing a startup that changes the behaviour of the user, it is vital to get feedback quickly on if they are open to such changes. Since Lean focuses on this quick validation, it would become a necessary addition to make to the SBMI framework if it would be applied to a startup. After all, a startup can not rely on previous data, users or financial means to facilitate the change that SBMI encourages.

This leads to the second problem of this model; it gives too little attention to financial aspect of the business. If the user wants to make a long-term impact, the business needs to be self-sustainable. This does require a significant analysis of the market, the costs, and other financial related aspects, which are just a minor component of the SBMI field or even being left out by SBMI models. Especially on the long-term aspect, SBMI was found lacking. Validation is not a major part of the SBMI foe;d, and it confines itself to the minor assumptions made during the process without dedicating at least a chapter to financial components. After all, if the competitor has a much cheaper product, it is very difficult to successfully launch an alternative. Normally, this should be an immediate dealbreaker for a startup if the user cannot calculate a pathway to sustainable business. If it is arguable that a larger scale the product would be able to compete, it is vital to determine the scale this would have to occur at, as well if the market has demand for that scale. This is contradicting what literature suggests, since most parties agree that the sustainable business models foster long-term prosperity (N. Bocken et al., 2019; N. M. P. Bocken et al., 2014; Geissdoerfer et al., 2018; Lüdeke-Freund & Dembek, 2017; Yang et al., 2017). Since startups have a high mortality rate of 90%, it is vital to focus some attention to the critical factors that make startups fail. The main factor is that the startup runs out of capital (Dennehy et al., 2016; Kalyanasundaram, 2018; Maital & Barzani, 2021).

Since the Lean model is developed for startups to require little capital, time or previous data, this entire problem is negated by using the Lean model. This is confirmed by this research report, since none of the validated hypotheses required additional investment besides time to confirm and the final hypotheses to decide between the go or no-go before the launch of the company are neither costly or time intensive. This drastically lowers the risk of the startup failing after money is invested.

This research report tries to manage this by assuming little investment, as is usually the case with startups, but SBMI hardly takes gaining new capital or sustainable revenue streams into account. One could argue that this is not relevant for the sustainability aspect, but this is contentious. Job stability has a big impact on the employees and is highly relevant on the societal impact (Adams et al., 2012; Hutzschenreuter et al., 2011). It could therefore be argued that all of the big factors that make a startup likely to fail, should be given sufficient consideration. Other important factors are no market need, got outcompeted, regulatory challenges, price to cost issues, team issues and timing (Maital & Barzani, 2021). This report discussed regulatory challenges, tried to verify the market need and looked into the price to cost issue. It was very noticeable that the SBMI leaves no room for the team. They either assume it to be an assumption or not relevant, whilst it is a very relevant factor. Therefore, this research report had to restrict our analysis of possibilities by setting the team in the 1.2 – Boundaries and assumptions. If the model allows for flexible teams or at least considers the skill sets required to perform the activities of the business and the limitations of these, the model would be more coherent. The most cited article relating to SBMI also makes no mention of startups and the usefulness of SBMI besides larger corporations (Bocken et al., 2014). It is likely that the problems of SBMI are less of a problem for corporations since they have more data to build their assumptions on, but this is a luxury startups do not have.

Another good aspect of SBMI is the fact that dependencies is such a large part of the model. Since a business operates in a society, it is guaranteed to have a lot of dependencies. Some of these will be business defining such as the market and the legal aspects. By defining the dependencies, the company can strive to utilise these dependencies to the fullest extent possible, increasing its potential for success.

Since the SBMI framework tries to be a coherent model, I would have liked to see more classifications of dependencies, even in its attempt to be generalised. After all, there are some that are universal, such as the previously mentioned market and legal aspects. In any business case, for startups and larger corporations, these would be relevant and thus should have a fixed place in the model, even if their impact on a specific business is small. The same would be the case for production and the team. Since the SBMI framework used in this research report was a generalised framework of the SBMI field, it is understandable that they did not include the team aspect, but this shows to be a mistake for startups. After all, the entire function of the SBMI field and this framework is to guide the company to a more successful and sustainable by being a business model.

As a solution to the stated problems of this SBMI framework, one could utilise SBMI models where financial focus is more of a focus (Shakeel et al., 2020). One such model which combines both is the Triple Bottom Line (Evans et al., 2017; Lee & Mao, 2015; Russo, 2008). The three main factors that a sustainable business model should combine are economic line, social line, and environmental line (Alhaddi, 2015). By finding the optimal point where these three overlaps, the company can construct the most sustainable business. These values are also mentioned in other papers, where this trinity is named Sustainable Value (Evans et al., 2017; Ueda et al., 2009). This approach could fix the problems

mentioned with the SBMI framework. However, the goal of this research report was to analyse the SBMI field as a whole by taking the most generalised framework by Bocken et al. (2019). They created their framework to encompass the main elements of the SBMI field. It would have been possible to analyse several models within the SBMI field, but this would not critically analyse the foundation that SBMI is built on.

This is why in this research report it was chosen to compare SBMI to Lean and by comparing them, suggest an effective framework to combine SBMI with Lean for startups. As shown, the Lean startup model could easily be combined with SBMI if one puts the entire SBMI aspect as a sub-group of the value proposition and it can therefore be used to fill in the gaps identified of SBMI. The flaws of SBMI are complemented by the strength of Lean. For a sustainability focussed business it is frequently the case that the value they generate is inherently linked to the sustainable goal they seek to achieve (Yang et al., 2017). One huge disadvantage of Lean is that the strategy is inherently focused on the short term: survival of the company and finding market traction are the main priorities. This does not necessarily translate into sustainability; this is the expertise of SBMI and the added value of SMBI.

The setup utilised in this research report was mainly using a SBMI framework as the leading framework, while using Lean to fill in the gaps. It might be more efficient to turn this around.

This research report therefore suggest that SBMI framework be implemented in the Lean Startup methodology. After the problem identification step in the early phases of the Lean framework, the core values are established. In this phase, the startup could perform utilise the SBMI framework, whether or not the founders think sustainability is truly a core value of their startup. It would be useful to get an overview of the parties involved (dependencies) and how they would influence the startup (Nature of dependencies). The startup could learn a great deal from the competitors on what action would lead towards success and the startup could further utilise the analysis to get in contact with the symbiotic or neutral parties. This allows the startup to create connections that can be used to co-develop the product. The startup could easily get feedback on their prototypes, inquire about the biggest problems of the parties, and generate presales with these symbiotic and neutral dependencies.
Furthermore, the startup could very well benefit from the analysis of the sustainability on the short and long term of their startup, product or service. An analysis of the impact allows them to select the most sustainable options and utilise the goodwill generated by framing sustainability as a core value with the dependencies. After these SBMI steps are followed, the Lean startup methodology would continue as intended with the development iterations. A visualization of this proposed framework is depicted in Figure 7.

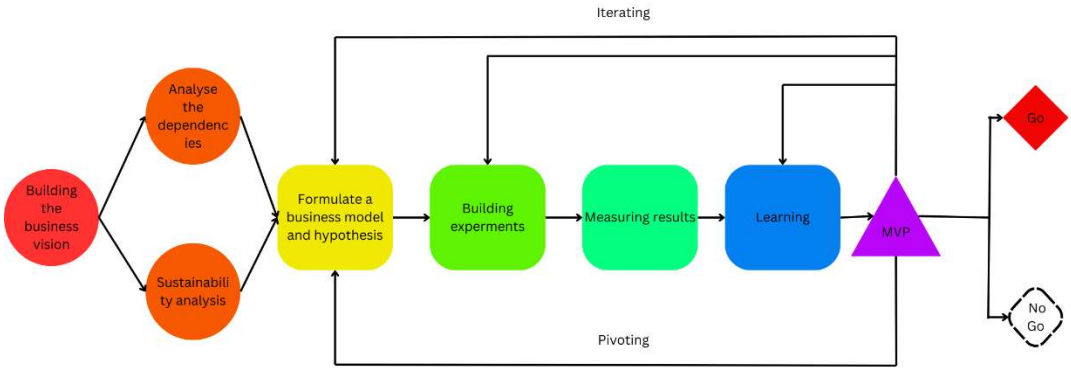

Figure 7: integration of the SBMI framework into the Lean methodology.

This proposed framework would combine the important advantages of both methodologies, whilst making the framework applicable for startups that may or may not have sustainability as a true core value. This would make the framework more inclusive and shows the benefits of sustainability for startups.

Despite the limited scope of the research report and the highly volatile nature of the market, based on the results of this research report it is likely that Kaumera would perform well on the market as a flame retardant and make a significant positive impact on society by doing so.

9 - Conclusion

In this research report it was analysed how Kaumera works as a flame retardant. Theoretically, there is no clear basis on why it works besides that Kaumera forms a lot of char, which is known to be an effective flame retardant.

We explored Kaumeras feasibility as a commercial flame retardant using Sustainable Business Model Innovation framework suggested by Bocken et al. (2019) compared to the Lean Startup methodology for startups. For these dependencies were identified and categorised. The symbiotic dependencies are Kaumera producers, clients, IP owners, academics involved and potential partners. Neutral dependencies are the legislative bodies, and the competitive dependencies are competitors. Kaumera was furthermore identified to have an 8 to 45 times lower carbon footprint compared to its competitors, which was also found via interviews to be an increasingly important metric for clients. Legislation was found not to be an obstacle since there are clear procedures for launching a flame retardant, but there are little infrastructure guiding producers to sustainable production.

Regarding the costs of production and the market conform selling price, it was found that Kaumera is not inherently cheaper or more expensive compared to competitors in a market which is full of competitors. It would therefore likely be a feasible product in the market, but it would not be easy to acquire a large market share from competitors.
It was also argued that Kaumera could have a positive impact on consumers footprint and the market by providing an environmentally responsible and effective flame retardant, without requiring clients to change their behaviour, since that was found to be disadvantageous for innovation.

This led us to conclude that Kaumera has the potential to be an effective, viable flame retardant, that can be launched in short period of time to target SMEs as clients. The UVPs of Kaumera would be effective if the price is competitive to the market.

It was concluded that the SMBI framework lacks vision on the economic field especially for startup cases. For sustainable startups the SMBI framework cannot be used without additional models that are purely financially focussed such as Lean. It is excellent to determine possible new UVPs that the company could utilise, but this is not applicable for startups that focus on establishing their core business.
The flaws of the SBMI framework can be complemented or fixed by combining the framework with the Lean methodology. This lead us to suggest a new framework where the SBMI framework is incorporated into the Lean methodology in the core value definition step of the Lean model.

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